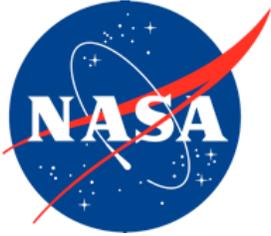


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Designing Flightdeck Procedures

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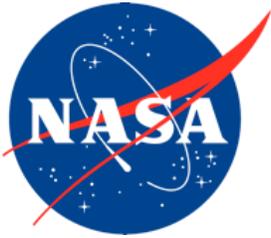
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Acronyms and Definitions

| | |
|----------|---|
| ACARS |Aircraft Communications Addressing and Reporting System |
| ADS-B |Automatic Dependent Surveillance - Broadcast |
| AFS |auto flight system |
| APU |auxiliary power unit |
| ASAP |Aviation Safety Action Program |
| ASIAS |Aviation Safety Information Analysis and Sharing |
| ASRS |Aviation Safety Reporting System |
| ATC |air traffic control |
| ATIS |Automatic Terminal Information System |
| CAST |Commercial Aviation Safety Team |
| CFR |Code of Federal Regulations |
| CRM |crew or cockpit resource management |
| datalink |means of connecting one location to another for the purpose of transmitting and receiving digital information. |
| ECL |electronic checklist |
| EFB |electronic flight bag |
| EGT |exhaust gas temperature |
| EPR |engine pressure ratio |
| ETOPS |Extended Range Operation with Two-Engine Airplanes (aka Extended Two-engine Operations) |
| FAA |Federal Aviation Administration |
| FCP |flight control panel |
| FCU |flight control unit |
| FDAP |Flight Data Analysis Program |
| FDM |flight data monitoring |
| FLCH |flight level change (autoflight system mode) |
| FMC |flight management computer |
| FMS |flight management system |
| FO |First Officer |
| FOQA |Flight Operations Quality Assurance |
| GPS |global positioning system |
| HDG |heading (autoflight system mode) |
| HUD |heads up display |
| ILS |instrument landing system |
| IT |information technology |
| KIAS |knots indicated airspeed |
| LOC |localizer (autoflight system mode) |
| LOSA |Line Operations Safety Audit |
| MCP |mode control panel |

N1turbine engine fan speed
NASANational Aeronautics and Space Administration
NextGenNext Generation Air Transportation System
NTSBNational Transportation Safety Board
NWANorthwest Airlines
OAToutside air temperature
PFpilot flying
PM.....pilot monitoring
POI.....Principal Operations Inspector
psi.....pounds per square inch
RNAVEn Route Area Navigation
RNP.....Required Navigation Performance
RPM.....revolutions per minute
SIDstandard instrument departure
SOPstandard operating procedure
TISTraffic Information Service
V speedairspeeds important for the operation of an aircraft
VMCvisual meteorological conditions
VNAVvertical navigation (autoflight system mode)
Vrefreference landing speed

Designing Flightdeck Procedures

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Loukia Loukopoulou⁴*

1.0 Executive Summary

1.1 Background

This report contains a summary of the results of a multi-year project funded in part by the Federal Aviation Administration to develop guidance on the process of developing procedures.

To conduct this work, we performed a far-reaching review of the existing literature on procedures that was focused on, but not limited to, aviation. We engaged in extended discussions with manufacturers of aircraft and equipment, airline pilots, airline managers, and regulators. We examined relevant voluntary safety reports and aircraft accidents, examined existing airline procedures, conducted jumpseat observations, and applied knowledge gained from over two decades of work with airlines.

A result of this work is summarized here in a 7-step process for developing procedures:

1. Determining when procedures need to be designed or modified.
2. Creating a procedure development process.
3. Understanding the relevant issues.
4. Crafting procedural solutions.
5. Writing procedures.
6. Implementing new procedures.
7. Evaluating and monitoring the conduct of procedures.

Each of these steps is described briefly in this summary and covered in more detail in the main body of this document. When the essence of this process has been followed, we have observed substantial improvement in procedures. In one carefully evaluated case, use of new procedures developed in accordance with the process described here, lead to an 84% decrease in observed errors by airline pilots.

1.2 Determining When Procedures Need to be Designed or Modified

Procedures may need to be developed or revised whenever new technology, personnel, or operations are introduced. Although manufacturers supply their customers with extensive procedures and

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checklists for operating their equipment, these procedures are usually limited to meeting the engineering demands of the technology. Manufacturers sell their products all over the world and cannot provide customers with procedures tailored to the customers' specific needs or operational environment. Hence, the introduction of new equipment often calls for new procedures. Changes in personnel may also require new procedures. For example, groups of pilots may develop informal techniques that support crew coordination. However, when airlines merge, pilots from the newly acquired company may have their own techniques. Hence, crews composed of pilots from the previously separate airlines may fail to be properly coordinated unless new procedures that formally support crew coordination are developed and implemented. Changes to the operation and the operational environment are also a reason to develop new procedures. For example, the introduction of new routes (especially to new international destinations) frequently calls for new procedures. Finally, operators may decide to revise procedures or create new ones when no change has occurred but operational problems have been discovered.

1.3 Creating a Procedure Development Process

Prior to beginning work on developing or modifying procedures, a systematic development process should be created. To be successful, developers must have access to expertise, resources, and information. Developing good procedures requires access to particular types of knowledge. Because procedures govern the interactions between pilots, their technology, and the operational environment, the procedure development process will always require access to expertise in technical domains, human factors, and operations. Procedure developers must have access to many different sources of information. This includes, but is not limited to, technical specifications, voluntary event reports, and automatically recorded flight data. In simple cases, a single individual may be able to develop the required procedures. In more complex situations, it will be necessary to engage an entire procedure development team with individuals selected for their particular knowledge and skills. In addition, procedure developers must create a realistic plan for carrying out *all* of the steps in the procedure development process and management must allocate the needed resources. Failing to allocate adequate time or resources to procedure development can cause the process to fail.

1.4 Understanding the Relevant Issues

Procedures guide the interaction between people, technology, and the operational environment. Hence, to devise effective procedures, developers must understand the capabilities of each of these components and the constraints that they impose on the operation. Developers must also understand how these components interact in the context of the tasks that must be performed. This basic concept, which we refer to as THE (Technology, Human, Environment) framework, has important implications. For example, it drives decisions about what information must be obtained before the procedure design process can commence and what qualifications will be required of individuals who are selected to be part of the procedure development team.

An important tool for building understanding of the relevant issues is a systematic task analysis. The focus of this analysis depends on the particulars of the situation. When new procedures are developed in response to the introduction of a new aircraft or other technology, changes in the operational environment, or adding a new personnel group, the primary causal factor is clear. Hence, the analysis can focus on how the new technology, environment, or people will affect the operation. When the procedure development process is commenced due to problem reports, it is often not clear what factors are involved. Hence, the analysis must focus on understanding the causes of the problematic events. However, in every case a systematic task analysis must be performed and this

analysis must consider multiple factors and how interactions between these factors might affect the operation. It is often tempting to focus exclusively on a single factor or to design procedural “band-aid” solutions that address only the surface problem without identifying the underlying causes. Such solutions often prove ineffective or even counterproductive. Only when underlying causes are identified and properly addressed, can effective solutions be crafted.

1.5 Crafting Procedural Solutions

Before beginning to craft a new procedure, the first question that one should ask is “Do we need this procedure?” Some tasks do not need to be proceduralized. In many cases, pilots may be allowed to perform actions as they see fit. Overproceduralization—creating and mandating the use of procedures when they are not needed—can be counter-productive and encourage non-compliance. Assuming that a procedure should be created, the next question to be asked is “What are the goals of the procedure?” In addition to accomplishing a task, procedures may have a variety of other goals such as conserving fuel or saving time.

These goals *of* procedures are distinct from the requirements *for* procedures. The primary requirement for any procedure is that it be correct. That is, it must produce the outcome that it was designed to produce. Furthermore, the procedure should be reliable; under normal conditions, the procedure should always produce the desired outcome every time the actions demanded by the procedure are executed. Also, the procedure should be robust; it should be usable across a reasonably broad range of circumstances. In addition, procedures should be resilient enough so that minor faults, errors, or unexpected departures from expected conditions can be easily overcome and the desired outcomes achieved.

In addition to these basic requirements, there are a number of subsidiary criteria (discussed in the main body of this document), such as procedural efficiency, consistency, usability, trainability, coordination, and integration that support these requirements. These subsidiary criteria are not independent of each other; in many cases one criterion may need to be traded off against another.

In addition to attempting to satisfy these goals and requirements, developers need to consider how the procedure will fit with other procedures. We make the distinction between “task procedures” which are focused on accomplishing a particular task (e.g., “Engine Start”) and “phase procedures” which are composed of multiple sequential or interwoven task procedures (e.g., “Before Taxi”), although the individual task procedures may not be identified by name. Also, developers should consider how the procedure would fit within the entire system of procedures. For example, a procedure system that imposes a strict regimen on the pilots in one operation but grants the Captain substantial discretionary authority in another similar operation is ripe for confusion and voluntary non-compliance.

Ideally, all procedures would be consistent with one another because they would have been designed to fall within an already established set of policies and an overarching operational philosophy. In addition to guiding procedure development, policies can be used to guide pilot actions when no procedure exists. One cannot anticipate every possible circumstance, and procedures cannot be developed for situations that are not anticipated. This structure by which an operational *philosophy* guides the development of *policies* that in turn guide the design of *procedures*, which control *practices* on the line, is referred to as the 4Ps. Like all topics mentioned in this summary, the 4Ps are discussed in more detail in the main body of this document.

In designing procedures, developers typically utilize different types of steps (described in the main body of this document) depending on what actions need to be accomplished. However, every procedure should clearly state 5 things: (1) what the procedure is designed to accomplish; (2) when and/or under what conditions the procedure should be executed; (3) who is responsible for executing each step in the procedure; (4) how, in detail, the procedure is to be performed; and (5) how to confirm that the procedure has been accomplished properly. The procedure developer should be able to specify these elements for each step in the procedure. However, it may be possible to simplify the content of the steps when one or more of these elements are consistent across the steps.

Procedures may also need to protect against adverse events. To avoid entering unacceptable states, procedure developers can use a combination of procedural *margins*, *barriers*, and *buffers*. Like physical barriers, procedural barriers are used to prevent undesirable actions. Margins are used to create some space prior to reaching the barrier, and buffers are used to avoid or reduce damage in case both the margins and the barrier are breached.

The procedure design process itself is cyclical, following 5 steps which are repeated as necessary: (1) develop a prototype task procedure; (2) analyze the prototype procedure; (3) eliminate conflicts between factors; (4) develop the encompassing phase procedure; and (5) test the procedure.

Testing the procedure is an important though often neglected step. Several different levels of formative testing should be used—from mentally running through the procedure to using the procedure in a simulated or actual flight. If the underlying issues have been properly analyzed and understood, it is likely that the original prototype procedure will be reasonably close to the final procedure on the first attempt. However, it is very difficult to predict the effects of all possible interactions between the technology, human factors, and operational conditions. The time to discover possible problems with a procedure is before the procedure is released for use. During the testing process, conflicts between the constraints imposed by the technological requirements, operational demands, and human factors limitations may be detected. When these conflicts are observed, the procedure should be modified to reduce or eliminate the problems. To eliminate or reduce these problems, one may: (a) alter the timing of individual steps; (b) transfer the responsibility for executing individual steps from one crewmember to another; or (c) alter one or more steps.

1.6 Checklists

In this document, we have devoted a section to checklists because of their special status among phase procedures. Checklists are a special type of procedure. On the flight deck, they are important tools for ensuring that the work is done correctly. Checklists are the prototypical example of procedures. They are often the form into which extended procedures are distilled, and the most common and most frequent form in which people interact with formal procedures. In addition to the design of the list itself, the checklist procedure includes the manner in which the checklist is to be executed (e.g., silent, challenge-and-response). Like any procedure, once a prototype checklist has been developed, it must be analyzed and tested using the same tools and methodology used with any procedure. All potential conflicts must be addressed, and the checklist must be thoroughly tested for feasibility and practicality.

1.7 Writing Procedures

Once procedures are developed, they must be effectively communicated. In this section of the main document, guidelines for the written communication of procedures are presented. These guidelines may apply differently, depending on whether the procedure under development is a detailed procedure or a checklist, and on whether it is a procedure/checklist for normal operations or for non-normal or emergency situations.

1.8 Implementing New Procedures

Implementation is an important, but often neglected, part of the procedure development process. For a procedure development process to be successful, the new or modified procedures must be effectively disseminated, properly trained, and appropriately promoted. In this section of the main body of this document, the issues that arise in implementing procedures are considered and a framework for the implementation process is briefly described

1.9 Evaluating and Monitoring the Conduct of Procedures in Practice

New procedures need to be evaluated prior to their release and following their implementation. Evaluation should not be regarded as an unnecessary task that can be performed if there is time and extra resources. Evaluation is a critical part of the development process and an important guard against the potential failure of the whole endeavor.

No matter how many smart people are working on a procedure design and development project, errors will occur and unintended consequences will materialize. The only way to catch mistakes and avoid costly new problems is to perform a careful evaluation. Developers might all agree that a set of new procedures is reasonable, but the procedures must be tested in a simulator, tried by other pilots, and tested on the line, where the world is much more complex than in the simulator. The new procedures must be given a chance to fail.

A well-designed outcome evaluation is a systematic way to find problems in proposed procedures before they are implemented. The evaluation allows for testing whether the new procedures work in the environment for which they were designed and with the people who will be using them. A thorough evaluation can discover problems that were not anticipated and generate solutions before the problems produce serious consequences. Systematic evaluation is not inherently difficult; data can be obtained from multiple sources including line observations, automatically recorded flight data, voluntary reports, and surveys. But like understanding the problems that led to the need for new procedures, a proper evaluation requires particular skills that may or may not be present in the development team or even in the airline. Hence, advance planning and resource allocation is required.

2.0 Procedure Design Process

2.1 Step 1: Determining When Procedures Need to be Designed or Modified

Operators are required to provide flightcrews with operating procedures (14 CFR 121.135), and with cockpit check procedures (14 CFR 121.315). Equipment manufacturers, especially aircraft manufacturers, supply their customers with extensive procedures and checklists for operating their equipment. However, these procedures are usually limited to the engineering demands of the technology, and are generic in their applicability. Manufacturers aim to sell their products all over

the world and cannot provide customers with procedures tailored to their specific needs, culture, and operational environment. Thus, operators often must modify and augment the manufacturer's procedures to suit their own needs. Although the manufacturer knows the engineering requirements of the equipment, the manufacturer is not an operator and may not be sensitive to all the demands of the environment in which the equipment will be operated.

Operators often find themselves in situations in which they must develop their own procedures or modify the procedures and checklists provided with the equipment they purchased. Often, these situations arise in response to changes in the operator or in the operation. In some cases, the change is sudden and large, as in the case of a merger or the introduction of NextGen-type operations (e.g., RNP/RNAV departures and arrivals). In other cases, new procedures might be required when incremental or small changes to any of the many aspects of the operation have accumulated to the point that existing procedures are no longer effective, as in the gradual transition of a fleet from classic models of a given aircraft to modern advanced models (e.g., a transition from operating mostly the B737-200/300/400 to operating the B737-700/800/900).

In general, the need to develop new procedures or modify existing procedures arise from four root causes:

1. *New technology.* The introduction of new equipment often calls for new procedures. The change can be a large one, as when the new equipment relies on a different design philosophy from the previously operated equipment; for instance, the introduction of an Airbus model to a previously all-Boeing carrier. The technology change might also be a small one as in the introduction of a new on-board printer for the ACARS, which requires a new procedure for replacing the paper. And the change can be somewhere in between as in the introduction of a new on-board tablet computer as an electronic flight bag (EFB) which not only requires a new procedure for its own operation, but is also a new way of presenting and interacting with other procedures.
2. *New personnel.* New people may also require new procedures. For example, a merger is likely to produce a large change in the backgrounds of the pilot population. The change may also be incremental, as when a pilot body of mainly former military pilots gradually changes into one composed mainly of pilots who came out of General Aviation. The desire to standardize the operation in spite of the different operational cultures from which the new people come and the different training these people received often leads to the need to develop new procedures.
3. *New operation.* Changes to the operation and the operational environment are also a reason to develop new procedures. For example, the introduction of new routes, especially routes to new international destinations, calls for new procedures, as would the introduction of ETOPS. Rising fuel costs may lead to decisions to employ single-engine taxi and use external power and air at the gate; these decisions would lead to the need to develop new procedures. Likewise, the introduction of new navigational capabilities and requirements such as GPS and RNP may change the operational environment and create a need for new operators' procedures.
4. *Observed operational problem.* Operators may decide to revise procedures or create new ones in response to a single event, incident, or accident or in response to a series of operational problems. Operators may decide to proactively change procedures in response to safety data or incident reports. The decision to modify or create procedures may be prompted by new requirements from regulators or recommendations from accident

investigators. Changes to procedures may also be prompted by the desire to improve operational efficiency in ways that are not directly related to safety.

2.2 Step 2: Creating a Procedure Development Process

Prior to beginning the task of developing or modifying procedures, a systematic process should be developed that will guide the developers. To be successful, the developers must have:

1. *Access to expertise.* Developing good procedures requires access to particular types of knowledge. Regardless of the particular circumstances driving the need for new or modified procedures (see Step 1 above), the procedure development process must start with a careful analysis of the factors driving the need to develop or modify the procedures and the implications of these factors. Because procedures govern the interactions between the pilots and the technology in the operational environment, the procedure development process will always require access to expertise in technical domains, human factors, and operations.
2. *Access to information.* Procedure developers should have access to many different sources of information. This includes ASAP and FOQA data as well as access to employee groups who might be affected by the procedures in question. These include cabin crew, maintenance, dispatch, and ground ops/ramp personnel in addition to pilots. Furthermore, the development team should have liaisons with the FAA/POI office, ATC, and relevant airports.
3. *Access to management.* Because each individual procedure resides within the context of the larger system of procedures (see discussion of the 4Ps below), the procedure development process will always require access to knowledge of the organization's philosophy and policies. If the philosophy and policies are in conflict or do not exist, the developers must be able to obtain resolutions from management.
4. *Access to resources.* Procedure developers need access to financial and personnel resources that are adequate for carrying out all of the necessary steps in the procedure development process. In simple cases, procedures may be developed by a single individual. In more complex situations, and most situations are more complex than they appear, it will be necessary to engage an entire procedure development team.

Often, flightdeck procedures are best developed by a team that brings different skills and perspectives into the design process. The team should include expertise in technology, human factors, and operations. In addition, because procedures are used by both Captains and First Officers, both perspectives should be represented on the team. To facilitate the implementation of changes to procedures, especially the implementation of large scale changes as in the case of a merger or the introduction of a new fleet, it would be beneficial to have on the team some representation of management and union, safety, training, and standards units. A single individual team member can cover multiple functions. For example, a senior Captain who is a Check Airman and a management pilot, or a junior FO who is a member of the union safety committee.

To support the work of the team, it is advisable to have an administrative assistant who can document the work of the team. This documentation is often crucial to the approval of the procedures, the design of needed training, and the implementation of any changes.

5. *Training.* When the team is assembled, even if the “team” is a single person, some training would be useful, including the content of this document and/or related sources. In particular, it is important for team members to understand the system of procedures and how they fit within the framework of existing policies, and the company’s overall operational philosophy. This understanding is necessary because the company’s philosophy and its policies guide the development of procedures, and because any new procedure must be consistent with this guidance as well as with all other procedures.
6. *Development plan.* The procedure developers must create a realistic plan for carrying out *all* of the steps in the procedure development process. Failing to allocate adequate time or resources to procedure development can cause the process to fail.

Once it has been decided that a change to existing procedures is needed or that new procedures must be designed, and a team has been assembled and trained, the process detailed below can guide the team’s work.

2.3 Step 3: Understanding the Relevant Issues

A procedure development process is typically established in response to: the adoption of new technology (e.g., new aircraft, FMS software upgrade), a change in the operational environment (e.g., a new route structure), a substantial change in personnel (e.g., a merger), or reports of one or more critical events (e.g., an accident, incident, or pilot reports).

When the procedure development process is established in response to the introduction of a new aircraft or other technology, to changes in the operational environment, or to adding a new personnel group, the primary causal factor driving the need for new or modified procedures is clear. Hence, the analysis will focus on how the new technology, environment, or people will affect the operation. It should also consider how interactions between this primary factor and the other factors will affect the operation. In these cases, data should be collected to determine the likely effects that these factors will have on the operation. It is often tempting to focus exclusively on a single factor. For example, when a new technology is introduced, procedure developers may be tempted to focus exclusively on addressing the requirements of the technology, ignoring human factors issues and operational constraints. However, procedures developed without a broad understanding of the task are likely to generate problems. These problems may be avoided if a broad task analysis is conducted first.

When the procedure development process is commenced due to problem reports, it is not necessarily clear what factors are involved. Hence, the analysis will focus on understanding the causes of the triggering events. In this case, the analysis does not have a clear starting point. The observed events may be caused by a single factor or multiple factors or be the result of a complex interaction. In this case, data should be collected to identify the causal factors and their effects. Whenever the procedure development process is triggered by a problem report, procedure developers may be tempted to design procedural “band-aid” solutions that address only the surface problem without identifying the underlying causes. Such solutions often prove ineffective or even counterproductive. When underlying causes are clearly identified and properly addressed, solutions can be crafted that are very effective and address what might initially seem like disparate problems.

For example, at first glance, the following two events appear very different from one another:

- A report of a rejected takeoff, after the crew failed to set the flaps.
- A report of a runway incursion, after the crew followed the wrong taxiway.

It is tempting to propose quick fixes for each of these cases: add a checklist item confirming the flap setting just prior to taking the runway; add a procedure step requiring the FO to call out the identifier of every taxiway before proceeding onto the it. However, on closer examination, these events may share an underlying causal pattern. For example:

- The crew in the rejected takeoff incident was performing their “before takeoff” procedures while taxiing to the runway; this procedure was interrupted at the point at which they usually set the flaps.
- The crew in the runway incursion incident was performing their “before takeoff” procedures when they were supposed to make a turn.

Hence, on closer examination, it is clear that these are not two separate problems but evidence of a single problem—a conflict between procedural demands and operational demands. The solution to this problem is resolving that conflict (e.g., by moving the point in time at which the “before takeoff procedure” is performed; see “Eliminating Conflicts” below).

Whether the procedure development process is motivated by a planned change or by an observed problem, procedure developers must gather and interpret the relevant information and conduct a task analysis. Potential sources of relevant information and a brief description of a task analysis methodology are presented in this section.

2.3.1 Sources of Data

The personal experiences of procedure developers are an important source of data. These data can be used to form hypotheses about the nature of the problem and to shape the search for more data. But there are a number of other sources of data that should be considered. It is important that data are sought from many sources, so that an accurate overall picture can be formed and the underlying causal factors identified.

2.3.1.1 Technical Information

Airline. Most airlines have a great deal of information available internally. In addition to the knowledge possessed by Technical Pilots in Flight Operations, other departments (e.g., Dispatch, Maintenance, Ground Operations, and Cabin) may also have individuals with substantial technical expertise. Pilot unions are another potential source of expertise in the company. In addition to their personal knowledge, these individuals may serve on national committees and working groups and have access to a wide range of information sources.

Manufacturers. In addition to engineering data and analyses, manufacturers typically maintain databases of problems experienced by their customers, solutions that have been tried, and the results of these interventions. These data are a good source of information about how the equipment has been used by other airlines that may be operating in similar operational environments with similar procedures.

Other Airlines. Airlines, especially their safety departments, often have open and active lines of communication. Under the safety umbrella, they work together to solve common issues. Contacting

other airlines to find out if they have faced similar situations and how they have addressed them can save time and help generate effective solutions.

Academic/Research Organizations. Data and information can also come from universities, government (e.g., FAA, NASA), and private research organizations. These organizations may be able to support the development process in many different ways, from providing technical information to conducting original research.

2.3.1.2 Operational Information

Line Observations. Line observations can be conducted to document the operational context. Many airlines have an ongoing Line Operations Safety Audit (LOSA) program. Procedures developers may be able to take advantage of existing LOSA efforts. If the necessary data is not already being collected, specific items may be inserted into the LOSA protocols. If the airline does not have an ongoing LOSA program, a line observation program targeted at the information needs of the procedure development process may be designed and conducted. As with any LOSA, the effort will provide unbiased information only when the observations are conducted to observe the operation and the operational context, and not to evaluate the flight crews.

Surveys/Focus Groups. Another way to gain insight into the operational context is through the conduct of surveys and/or focus groups. However, constructing good surveys and running useful focus groups requires methodological knowledge and skill. Although asking questions may seem straightforward, poor question design can lead to misleading results. Developers should consult with knowledgeable sources before attempting to use these techniques.

Incident and Accidents Reports. Incident reports from NASA's Aviation Safety Reporting System (ASRS): <http://asrs.arc.nasa.gov/>), carrier Aviation Safety Action Program (ASAP) programs or other internal reporting systems, and the FAA Aviation Safety Information Analysis and Sharing (ASIAS): <http://www.asias.faa.gov>) database are all excellent sources of data. Databases usually come with sophisticated search tools. Reporters often include their own analysis as to why the reported events took place, though these explanations should not be automatically accepted.

Accident reports are also a good source of information. Fortunately, there are very few accidents, but those that are thoroughly investigated can provide insights into normal operations and can also suggest the kind of questions that should be asked when analyzing other data. Reports can be downloaded e.g., from the NTSB database (http://www.nts.gov/_layouts/nts.gov/aviation/index.aspx) or Skybrary (http://www.skybrary.aero/index.php/Main_Page) (which includes reports from all over the world). And there is a host of other sources with information about aviation safety issues and events from around the world (e.g., the Flight Safety Foundation website (<http://flightsafety.org/>) and the CAST, Commercial Aviation Safety Team website (<http://www.cast-safety.org>)).

FOQA/FDAP/FDM. Programs such as Flight Operations Quality Assurance (FOQA), Flight Data Analysis Program (FDAP), and Flight Data Monitoring (FDM) use the data recorders available on the aircraft to support carrier operations. These data can be used to determine details of what happened during a flight. For example, these data can be used to determine what the aircraft was doing during an unstable approach, a rejected takeoff, or a takeoff with the APU running. However, the recording devices cannot capture the operational context (e.g., weather, cabin crew activities)

and cannot tell why events happened. To help construct the whole picture, these data must be combined with data from other sources, such as ASRS and ASAP.

2.3.1.3 Data Analysis

Once data is gathered, it must be analyzed to identify the underlying patterns. Different types of data require different types of methodological expertise. This expertise often can be found within the airline but may need to be obtained elsewhere. What procedure developers must do is to ask the right questions. These questions can follow the “5 Whys” process. The goal of data analysis is to form a detailed, comprehensive, and correct picture of the common patterns across events and their underlying causes. To reveal such underlying causes, the question “why” is asked at least 5 successive times. Of course, there is nothing magical about the number 5. Complex issues may require more than 5 questions, but asking “why?” five times is a good place to start.

For example, in response to a reported rise in the number of unstable approaches, one might ask some version of this series of questions:

1. Why were the approaches considered unstable?
 - According to FOQA data, the aircraft involved did not meet the stabilized approach criteria at the mandatory 1,000 foot go-around gate.
2. Why did the crews not go around per procedure?
 - Perhaps no command to go-around was given.
 - Perhaps the command was ignored.
3. If the required go-around command at 1,000 foot was not made, why wasn't it made?
 - Given ASAP data, perhaps the crew realized that they were not meeting the stabilized approach criteria and deliberately chose to deviate from the approach procedure requiring a go-around—a case of selective non-compliance.
 - Perhaps the crew did not realize their unstable condition until very late in the approach.
4. If the crew decided to deviate from the procedure, why did the crew think that it would be acceptable to deviate from the procedure?
 - Given relevant weather and airport data, perhaps the crew decided that given the good visibility, the long runway, and the healthy headwind, a safe landing could be made.
5. But, why did the crew decide that they should ignore the mandated procedure?
 - Given responses to a survey of the pilot group, perhaps the recent company emphasis on fuel savings (that led to reduced minimum fuel requirements, extensive tanking of fuel from cheap stations, and a push for single-engine taxi) has also led crews to avoid “expensive” go-arounds.
6. Why do the pilots feel that a go-around would be considered so expensive that safety could be compromised?
 - Given pilot input through focus groups and a survey, perhaps the crew thought that safety wasn't really compromised, that the go-around requirements are too strict, and that the company is much more concerned with costs and on-time performance than with such minor violations.

Of course, other “why” questions and answers are possible. The answers to the questions are determined by data, not arguments. The subsequent questions depend on the answers to the previous questions.

Different answers to the different “why” questions would suggest different potential interventions. From negotiating with ATC about early approach clearances to negotiating with management about fuel saving measures, there could be a wide range of relevant interventions to reduce the number of unstable approaches. Furthermore, the analysis of the seemingly specific problem of unstable approaches can easily lead to the recognition of much larger systemic issues such as the impact of fuel saving measures on pilots’ decision making.

Often, a thorough analysis will reveal that pilots may not fully understand the rationale for a policy or procedure. Asking “why don’t pilots understand that rationale?” could reveal that the procedures were introduced without sufficient effort to educate the pilot group on the rationale for the change. Thus, a thorough analysis—driven by insisting on asking “why?”—can lead to interventions that solve the original problem and improve other operations as well.

Although it might seem quick and simple, an additional procedure or an added line item on a checklist may not always be the best solution.

2.3.1.4 Task Analysis

In some cases, it may be necessary to construct procedures from scratch. But in most cases, there will be an existing procedure that needs to be revised or adapted to work within the airline operation. For example, an airline may want to purchase a new aircraft or install a new piece of equipment in aircraft that are already on the line, open routes to new destinations, or merge with another airline. In all of these cases, there are likely to be existing procedures from manufactures and/or the airline that can serve as a starting point for the development of the new procedures. However, whether there are existing procedures or not, the first step in developing a procedure is to become familiar with the requirements of the mission that will be performed, the constraints imposed by the operational environment, and the capabilities and limitations of the technology and people that will be engaged in the task. This requires a systematic task analysis in which these components are analyzed. Depending on the scope of the proposed changes, this analysis may require a substantial amount of effort. However, once developed, a completely new analysis does not need to be produced for every proposed change. The existing work may be modified as needed.

Task Analysis Framework

To begin the analysis, the mission requirements for each part of the operation that the proposed change will affect need to be specified at a moderate level of granularity. For example, if a proposed change were to affect the climb phase of flight, then the essential requirements for the operation during this phase would be listed (e.g., acceleration, climbing at climb thrust, heading changes, level off at cruise altitude, etc.). This step in the procedure development process produces a framework that can increase in detail as necessary. In some cases (e.g., the implementation of a new flight release format), this step will be focused on one part of a single phase of flight. In other cases (e.g., installation of a new datalink communication system), the entire operation from gate to gate may be affected. Because timing is crucial in understanding how various factors will affect the procedures, these requirements and all other parts of the analysis must be delineated chronologically.

Once the mission requirements have been broadly defined, the requirements imposed on the procedure by the capabilities of the technology, humans, and operational environment must be specified. Although no single one of these three components will take precedence in all situations, the constraints imposed by one component, often the technology or the operational environment, will appear most salient. It is critical to be able to ignore that appearance, and allocate proper time and attention to all three components. The analysis of each component is briefly summarized below.

Operational Environment

Designing good procedures requires an understanding of the effects of the environment outside the cockpit on operations. The operational environment includes the physical and non-physical factors that may impact the operation. Physical factors include issues such as terrain, airport layout, and weather. Non-physical factors include interactions with support personnel—such as the cabin crew, ground crew, and dispatch—organizational factors—such as company policies, and culture—and regulatory factors—such as air traffic control instructions and airspace restrictions. For example, the climb phase could be affected by physical factors such as winds, terrain, and convective activity, by interactions with support groups such as advising the cabin crew when to begin service, organizational factors such as a fuel-savings policy, and regulatory factors, such as noise abatement procedures, SIDs and ad hoc ATC instructions to level off and/or change headings.

Analysis: To determine the potential effects of the operational environment on an operation, one can start either with an analysis of the environment or with an analysis of the operation. This information can then be used to mold the actions required to deal with these effects into procedures. If the airline is already conducting operations in the planned environment, the effects of physical, support, organizational, and regulatory factors on the operation can be determined by observing line operations and identifying the ways in which the operations are affected by these factors. If the airline is not operating in the environment, this information will need to be obtained from other sources (e.g., experience of other airlines). The effects of environmental factors on the operation can then be added to the task analysis framework.

The process for analyzing the effects of the operational environment involves answering 4 questions:

1. What physical phenomena must be taken into account and how might they affect the operation?
2. What interactions with support personnel may occur and how might they affect the operation?
3. What organizational factors must be taken into account and how might they affect the operation?
4. What regulatory constraints are present and how might they affect the operation?

Application: In an ideal world, flight operations, and hence procedures, would be linear, predictable and controllable. Step B would always follow Step A, and Step C would always follow Step B. Events would always be predictable, information (such as ATC clearances) would always be available when needed, and all activities would be under the direct and complete control of the flight crew. However, this ideal world does not exist. Procedures must reflect the realities of the operation, not a fictitious ideal world.

In general, several approaches can be taken when dealing with a complex and unpredictable operational environment:

1. Simplify the environment or interactions with it. For example, it may be possible to simplify the operational environment by altering routes to avoid complex airspace or hazardous areas. Interactions with the environment may be simplified by eliminating activities (e.g., calls to dispatch) or changing when tasks (e.g., climb checklist) are performed to quiescent periods.
2. Build conditional procedures. It may be possible to build procedures that include conditional (i.e., if x then y; if not x then z) statements to deal with a complex environment. For example, “IF the OAT is between +2C and -24C AND there is visible moisture, select Anti-ice ON.”
3. Build robust procedures. It may be possible to build robust procedures that will work effectively despite variations in the operational environment. For example, to avoid needing to determine where ADS-B is available, a procedure could state “Select ADS-B ON. Note: Do NOT rely on ADS-B TIS information. ADS-B may not be available.”
4. Build resilient procedures. Incorporate steps into procedures and/or add checklists that will facilitate recovery from problems induced by unpredictable or uncontrollable aspects of the environment. For example, a procedure may call for spooling up jet engines on approach in the event that power is required quickly for an unanticipated go-around.
5. Build policies instead of procedures. Provide guidance through policies when the environmental conditions make procedure development impossible or impractical. For example, rather than attempting to write procedures that specify the FMS mode to be selected in all possible cases, the airline could adopt an “automation policy” that sets guidelines for making the decision of which mode to select and leaves the choice to the pilot.

Technology

All machines have capabilities (things they are designed to do) and limitations. Depending on the equipment, these limitations may include physical limits (e.g., weight, altitude, temperature, humidity, etc.), functional limits (e.g., range), and processing limits (e.g., operations per unit of time, memory capacity) among others. In many cases, machines have an optimal range in which they operate best. Sometimes, the technology can be made to operate outside this optimal range, but with degraded performance. Good procedures keep the technology within its optimal range. Designing good procedures requires an accurate functional understanding of how the technology operates.

Analysis: Understanding how a piece of technology functions does not require understanding the underlying engineering. However, it does require understanding all of the relevant behaviors—states and modes—of the machine. This means that the function of each state/mode and its associated behaviors, the causes and effects of transitions between system states, how pilots can interact with the system, the meaning of displayed indications, and the effects of machine failures and external disturbances on the machine’s behaviors must be understood before procedures utilizing the technology are developed.

The process of analyzing technology involves answering 7 questions:

1. What are the possible states, configurations, or modes of the machine, what does each of them control, and what are the limits of each? For example, which control surfaces

- are operated by which hydraulic system? In VNAV Path, is speed controlled by pitch or thrust?
2. What conditions or targets (e.g., airspeed, altitude, thrust level, etc.) trigger the transitions between states or modes? For example, does automatic fuel transfer stop at a particular quantity level or after a given number of minutes of flow? At what point does HDG transition to LOC when LOC is armed for the approach?
 3. What are the possible sequences of state transitions? That is, what will happen when the targets are achieved and what will happen if they are not achieved? For example, if the main tanks are within 50 lbs of each other, will fuel transfer stop? If the localizer signal is lost, what will the AFS command?
 4. From what sources (e.g., sensors, FMC, MCP/FCU/FCP) does the system obtain information and what will happen if these sources fail? For example, if a fuel flow sensor fails, will fuel transfer cease? Under what conditions does the AFS obtain altitude from the barometric altimeter rather than the radio altimeter? What happens if the radio altimeter fails?
 5. How long (what is the range and under what conditions) will it take for the system to achieve the desired effect? For example, how long will it take for the landing gear to extend and lock in an aging aircraft? How long does it take to transfer fuel from one tank to another?
 6. Under what conditions does each state or sequence produce optimal, sub-optimal, or dangerous behaviors? For example, if a main tank leaks fuel, will fuel be automatically transferred into it and then lost? In a late descent, under what conditions will VNAV make the next crossing restriction? If an inflight hydraulic leak impacts 2 of 3 hydraulic systems, how will it affect the remainder of the flight? How does an electrical reconfiguration due to a generator failure impact the autoflight system?
 7. What steps can be taken to encourage optimal operation and avoid dangerous states? For example, how should a “throttle bump” be conducted to verify that the flaps are in the takeoff configuration, and what would it really test?

Answers to these questions are typically available from the manufacturer. Once this information is obtained, the desired sequence of modes/states and alternatives can be incorporated into the task analysis framework.

Application: Although manufacturers typically provide procedures for their products, the manufacturer may not have considered the characteristics of all of the possible operational environments or how their equipment will work with other technologies installed in the aircraft. Hence, manufacturers’ procedures frequently need to be adapted or modified. To obtain optimal performance and avoid dangerous states, it may be necessary to add procedural steps that ensure that relevant indications are checked and that operational margins are maintained. In some cases, several different actions can be used to accomplish a task. The optimal configuration may depend on particular circumstances. At this point in the analysis, the alternate states/modes and the relevant conditions should be incorporated into the task analysis framework.

Humans

Like machines, humans have capabilities and limitations. Good procedures build on human strengths and compensate for human limitations, just as they do with the capabilities and constraints of the technology. Many problems in operations arise from conflicts between human limitations and the demands placed on the pilots by procedures that may take into account the requirements of the technology and the demands of the operational environment but do not properly account for human limitations. Thus, understanding the strengths and limitations of the human is critical for designing good procedures.

Analysis and Application. Humans are very complex. Although it is difficult to produce a comprehensive analysis of human capabilities and limitations, a useful picture can be obtained by using a type of Cognitive Task Analysis. Human functioning can be analyzed into a set of processes. The procedure developer can then determine how these processes will be utilized in the operation as the pilots interact with the technology and the operational environment. Procedures can then be designed so that human functioning on each of these processes is kept safely within limitations. Below, these “human factors” are grouped into three categories: basic processes that are likely to be involved in all activities, higher-order processes that will be involved in many but not all activities, and inter-individual processes that may influence any activity but will be particularly salient when the pilots are interacting with each other and with other people. Examples of common issues are provided under each heading.

Basic processes:

1. *Bio-psychological factors.* Humans are built to operate within a relatively narrow range of conditions. To function well, our bodies need to be kept at an appropriate temperature, with continual access to oxygen at appropriate concentrations and pressures, and with water, food, and sleep every few hours. Furthermore, our bodies are set to function on a regular circadian rhythm – a daily cycle of light and dark, wakefulness and sleep. If these limitations are violated, physical and cognitive performance will be impaired. Procedures should aim to keep the pilots within their optimal range of biological conditions. For example, procedures should not require both pilots to be continually at their stations during turn-arounds so that they are unable to obtain food for extended periods of time.
2. *Perception.* Perception refers to the physiological and psychological processes involved in sensing the outside world and the translation of these sensations into useful information. Perceptual processes are subject to a number of biases and illusions. Expectancy effects (e.g., seeing what is expected rather than what’s actually there) are particularly powerful. Procedures should be designed to avoid these biases when possible and to compensate for them when they cannot be avoided. For example, procedures that require both pilots to verify a value (e.g., flap setting) are more likely to be resilient than procedures that require only one pilot to check the setting.
3. *Attention.* Although people can perceive signals (e.g., light, sound) simultaneously from multiple sources, they can focus attention on only one source at a time. Attention is drawn by change (e.g., flashing alerts, alarms) and directed to items of perceived importance. Attention will shift when the available information does not change. Procedures should avoid requiring pilots to maintain attention on unchanging displays. Procedures should direct pilots to appropriate sources of information for each task; “multi-tasking” — attempting to perform multiple tasks at the same time — should be

avoided. For example, when more than one task must be accomplished at the same time, the tasks must either be divided between the pilots or the steps for each task interleaved so that the steps that require attention to one task do not co-occur with steps that require attention to the other task.

4. *Memory*. Memory can be divided into two major components: *working* memory and *long-term* memory. Long-term memory holds our store of knowledge. It has no known capacity limits. However, our memory for facts and figures (declarative knowledge) is much less resilient than our memory for how to do things (procedural knowledge). When not used, access to declarative knowledge may be lost. Working memory is a limited capacity mental “workbench” in which we can hold and manipulate small amounts of information (reliably, only up to 3 propositions). *Prospective memory*—the memory of the intention to do something at a later time—is particularly vulnerable. Deferred items are easily forgotten. Procedures must respect the limits of human memory. They should not require pilots to remember and/or mentally manipulate more than a few bits of information at any time. Memory cues (e.g., do-lists) should be provided for procedures that are rarely performed. Procedures should be designed to limit the likelihood of interruptions and other events that may lead to deferred actions. When these are unavoidable, checklists should be provided for critical items to catch prospective memory failures.
5. *Comprehension*. Comprehension refers to understanding the meaning of what we perceive and remember. Information may be accurately perceived and/or remembered but misinterpreted. When this is reasonably likely (e.g., smoke in the cockpit), procedural support should be provided (e.g., a branching problem identification flow chart) to help the pilots interpret the perceived information.
6. *Emotion*. Emotions are complex psychophysiological processes. Different emotions are associated with different psychophysiological responses that may adversely affect cognitive processing in different ways. Though difficult to predict, people’s potential emotional responses should be taken into account when designing procedures. For example, anxiety may lead to narrowed attention and decreased working memory capacity. If a procedure (e.g., an emergency procedure) may need to be executed while the pilots are likely to be anxious, it should not require that the pilots perform complex mental calculations (e.g., procedures should be designed so that no individual step relies heavily on working memory).

Higher-order processes:

7. *Situational awareness*. Situational awareness is commonly divided into three levels: 1) the perception of critical elements in the environment; 2) the comprehension of their meaning; and 3) the projection of their status into the future. Maintaining situational awareness depends on attention and working memory. When these processes are impaired, situational awareness will be impaired. Whenever continual situational awareness is critical (e.g., during taxi), procedures should not require that the pilots devote their attention to other tasks (e.g., conducting another procedure).
8. *Problem solving*. Many procedures are designed to assist people in finding solutions to specific problems. In normal procedures, one can often delineate the order of tasks and the specific steps that must be taken to solve the problems (e.g., weight and balance, V-speeds, fuel required, top-of-descent points). Procedures should provide guidance for

determining what the problem is (e.g., determining whether smoke is the result of air conditioning or electrical fire), and general approaches to solving these problems.

9. *Decision-making*. Decision-making refers to the process of generating, evaluating, and selecting between alternative courses of action. Procedures can guide pilots in determining what information to consider and how it should be integrated to arrive at a decision. For example, a cold weather operations procedure could include steps that would guide pilots' information gathering and decisions regarding the feasibility of departing given the weather conditions and the likely delay between de-icing and takeoff.
10. *Task management*. Pilots often must perform a number of different tasks within the same time period. Procedures can assist pilots in task management by directing the distribution of tasks during the flight, and by guiding the pilot in choosing appropriate strategies for managing tasks when the workload is high. For example, rather than using a floating "before takeoff" checklist to be performed somewhere between the gate and the runway, the items on the checklist can be divided between "before taxi" and "at the line" checklists, thus managing the workload and avoiding potential conflicts between the need to perform all of the items and other duties (e.g., taxi).

Inter-individual processes:

11. *Communication*. Communication requires that thoughts be translated into spoken or written (typed) words that are then transmitted to someone else. The "receiver" must then decode the message to comprehend what the sender intended to communicate. Problems can occur at any step in this process. Procedures should be designed to reduce the likelihood of communication errors. For example, when critical information is being communicated, standardized language may be required; sterile cockpit rules may be applied; and readback and verification steps may be included in the procedure.
12. *Shared mental models*. With an accurate *shared* mental model, a crew can work together efficiently with minimal effort. Without a shared mental model, communication and coordination may be difficult. Whenever having a shared mental model is particularly important, procedures can be designed to ensure that critical information is shared. For example, departure and approach briefing procedures can specify what information (e.g., intended approach, speeds, and configuration) must always be explicitly communicated.
13. *Roles*. In the commercial aviation cockpit there are usually two crosscutting role structures: one fairly stable and based on rank (Captain, First Officer) and the second transitory and based on the tasks at hand (Pilot Flying, Pilot Not Flying/Pilot Monitoring). Procedures that clarify the different duties and decision-making authority that are active while the procedure is being conducted allow the work to be easily coordinated and avoid potential conflicts.
14. *Culture*. The effect of culture (whether national, ethnic, or organizational) is pervasive primarily because it strongly affects our mental models, which in turn affect how we interpret new information and make sense of the world. Culture can influence our perception of what is happening, and our expectations about what will happen and what should happen. Procedures should be written with an eye towards avoiding reliance on cultural assumptions that may not be shared by all pilots. For example, following a merger, pilots from different organizational cultures often are required to operate together. If their expectations differ (e.g., whether the FO must wait for the Captain to initiate procedures or whether FOs have the responsibility to initiate procedures on their

own), dangerous situations can occur (e.g., the FO waiting for the Captain while the Captain wonders why the FO is not conducting a procedure). A procedure that clearly specifies who will initiate the procedure can avoid this problem.

Analyzing the effects of human factors on an operation involves answering three questions:

1. What human factors processes are most relevant in performing this particular part of the operation?
2. What are the constraints imposed by each of these factors?
3. How do these constraints affect the operation?

Task Analysis Tool

At this point in the task analysis, the development team should have the information required to link the requirements of the mission to the constraints imposed by the operational environment and the capabilities and limitations of the technology and human pilots. One way to do this is by using a simple table or spreadsheet as demonstrated in Figure 1. In each cell, the imposed constraints, observed problems, and potential solutions can be detailed.

| Time | Task | Environment | Technology | Humans |
|------|------|-------------|------------|--------|
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Figure 1. Simple Aviation Task Analysis Tool template.

This basic framework can be expanded as necessary to encompass multiple components within the technology, human, and environment categories and it can be used for both task and phase procedures (see Figure 2). It is also possible to use Captain and FO if more relevant than PF/PM, or add separate columns for possible errors by each crewmember (see Developing Procedures section below).

| Time | Task | Environment | | | Technology | | | Humans | |
|------|------|-------------|---------|------------|------------|---------|----------|--------------|------------------|
| | | Physical | Support | Regulatory | Engines | Control | Guidance | Pilot Flying | Pilot Monitoring |
| | | | | | | | | | |
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Figure 2. Expanded Aviation Task Analysis Tool template.

When multiple phases must be considered, the structure will become cumbersome unless different phases are described on separate sheets (see Figure 3).



Figure 3. Aviation Task Analysis Tool by phase of flight.

These tools are designed to assist in the conduct and documentation of the systematic task analysis. But it is the task analysis not the tool that is important. Only by examining the requirements of the mission in the context of the constraints placed on the operation by the requirements of the technology, the demands of the operational environment, and the limitations of the human pilots can developers be reasonably confident in their understanding of the circumstances that the procedures are meant to address.

2.4 Step 4: Crafting Procedural Solutions

Once the goals of the procedure are clear and the constraints and requirements imposed by the technology, humans, and operational environment have been determined from the task analysis, the process of constructing the procedure can begin. A general approach to the development of procedures is described here divided into five sections. To be effective, all procedures must satisfy several requirements. Therefore, the first section details the requirements for effective procedures. One of the requirements is that the procedures be consistent with other procedures and with existing company policies as well as the overall company operational philosophy. Thus, the second section outlines the 4Ps framework of Practice, Procedures, Policies, and Philosophy. The third section describes the general structure of procedures. In the fourth section, the process of constructing procedures is detailed. Because checklists are a special type of procedure and fulfill a specific and important role in aviation, the final section is devoted to the construction of checklists.

2.4.1 Requirements for Procedures

Procedures are developed to accomplish specific tasks. The primary requirement for any procedure is that it be *correct*. That is, it must produce the outcome that it was designed to produce. Furthermore, the procedure should be *reliable*. Under normal conditions, the procedure should always produce the desired outcome every time the actions demanded by the procedure are executed. Also, the procedure should be *robust*. It should be usable across a reasonably broad range of circumstances. In addition, the procedure should be *resilient*. Things don't always go as planned. Technical glitches may occur; people may make mistakes; the operational environment may change. Procedures should be *resilient* enough so that minor faults, errors, or unexpected departures from expected conditions can be easily overcome and the desired outcomes achieved.

2.4.1.1 Primary Requirement

Thus, every procedure has a primary requirement: procedures must be:

Correct. If the procedure is followed, the specified actions will yield the desired outcome.

2.4.1.2 Basic Requirements

In addition, procedures have three basic requirements:

Reliable. Under normal conditions, whenever the specified actions are accomplished, the desired outcome will be obtained. For a procedure to be reliable, it should minimize dependencies on unpredictable or uncontrollable agents and events. Some dependencies cannot be avoided, such as depending on dispatch for the release or for weight and balance information, or depending on baggage handlers to load the aircraft and close the cargo doors. But procedures that contain such dependencies are less reliable than procedures that are fully under the control of the crew because steps cannot be incorporated into the *cockpit* procedure that will ensure that these actions are performed properly and finished when needed. Similarly, procedures that rely on retrieving a long list of actions from memory are less reliable than procedures that do not rely heavily on memory.

Robust. The procedure will succeed in achieving the desired outcome despite minor expected variations in the performance of the equipment, the actions of the human operators, or in the operational environment. Thus, a procedure that requires shutting down the APU before every takeoff is less robust than a procedure that allows leaving the APU running should that be required for passenger comfort during a packs-off maximum-performance takeoff. Similarly, a procedure that can only be used during day VMC is less robust than a procedure for the same task that can be used under all time and weather conditions.

Resilient. The procedure will succeed in achieving the desired outcome despite errors or unexpected variations. For example, a procedure that includes a step in which the pilot flying verifies the pilot monitoring's input to the FMS before it is executed is more resilient than a procedure that lacks this step. The verification step allows errors to be caught and the operation to proceed as desired.

A procedure is either correct or not. However, reliability, robustness, and resilience are matters of degree. The more reliable, robust, and resilient the procedure, the better the procedure.

2.4.1.3 Subsidiary Criteria

In addition to the basic requirements above, there are a number of subsidiary criteria that support these requirements. These subsidiary criteria are not independent of each other and one criterion may need to be traded off against another. Also, the order of priorities among these criteria depends on the particular procedure in question. In general, procedures should be:

Efficient. The execution of the procedure should require the least amount of time and effort possible. Inefficient procedures can reduce the available cognitive and other resources that may be needed to properly execute the procedure and conduct other activities. It might be possible to accomplish a given task in one of several different ways; all ways are equally correct and similarly reliable, robust, and resilient but they differ in the amount of time required to complete them. The procedure that requires the least amount of time is the most efficient procedure. For example, the retraction of flaps after takeoff may be accomplished

following a procedure that requires the Pilot Flying to make the callouts for each stage of flap retraction and the Pilot Monitoring to execute the actions. Alternatively, the procedure could require the Pilot Flying to make the initiating callout and the Pilot Monitoring to silently retract the flaps according to the speed schedule and only announce the completion of the procedure when the flaps are fully retracted. The second option takes less time and attention from the Pilot Flying than the first and is thus more efficient. However, this procedure may compromise crew coordination (see the Coordinated criteria described below). Trade-offs may be inevitable.

Useable. The procedure should be “easy” to use. Procedures that rely on easily performed actions in easy to follow sequences and utilize well-learned cognitive associations are perceived to be “natural” or “intuitive” and are less likely to result in errors. For instance, flows that are based on the spatial organization of the cockpit, such as the procedures typically used during preflight to confirm the status of aircraft systems, are more usable than flows that lack organizational cues.

Coordinated. To complete the designated task, some procedures require the actions of more than one individual. In these cases, the procedures should incorporate steps that ensure adequate coordination (e.g., good communication, shared information and mental models) between the individuals involved. What’s more, procedures that support CRM are better than procedures that ignore CRM. Thus, a procedure that includes both crewmembers is preferred over a procedure that leaves one crewmember out of the loop. When the workload must be divided between the crewmembers such that each must act independently, coordinating steps should be used to periodically bring both crewmembers up-to-date on the state of the aircraft and the state of the mission. For example, if the First Officer must go “heads down” during taxi to program an amended departure clearance, upon completion of the programming task the Captain should brief the FO on the progress of the taxi and any ATC communications, and the FO should confirm with the Captain that the programming task was performed correctly.

Integrated. Procedures should be well integrated into the workflow. Individual procedures rarely exist in isolation. The individuals charged with executing the procedure may be engaged in other activities. The procedure may require interactions between the flight crew and cabin crew, ground personnel, or air traffic control. The equipment needed to execute the procedure may be needed for other tasks. Hence, although a procedure may be correct and reliable in isolation, it may fail if it is not integrated with the other demands placed on the technology, humans, and operational environment. For example, a procedure that requires the crew to confirm that all cargo doors are properly locked during the preflight walk-around isn’t well integrated with the reality of loading late bags.

Consistent. Individual procedures should be consistent with other procedures and with the relevant policies and overall operational philosophy. For instance, procedures should be clear and consistent in the allocation of responsibilities and authority, in structure, and in phraseology. Inconsistency leads to procedural deviations including intentional and unintentional non-compliance. For example, if one procedure requires the Captain to always be in control of the aircraft during taxi, it would be inconsistent to have another procedure that requires the Captain to make all changes to the programmed route. Similarly, if one checklist procedure requires the PM to read the challenge and the PF to respond, it will be inconsistent to have another checklist procedure that requires the PF to read the challenge

and the PM to respond. One way to encourage consistency across procedures is to have policies and an operational philosophy in place to guide procedure development.

Trainable. Procedures should be easy to train. For instance, a procedure that includes several simple steps is easier to train than a procedure that includes complicated steps even if there are fewer of them. Also, procedural sequences that lend themselves to a logical story-like progression of steps are easier to train than sequences that seem arbitrary. For instance, configuring several systems, one system at a time according to the functional dependencies within each system is a sequence that would be easier to learn than configuring these systems in parallel one step at a time. Although a procedure once learned, may comply with all of the other criteria, if the procedure is difficult to learn, training the procedure will put a strain on the individuals tasked with performing the procedure and on the organization.

Adaptable. Procedures should be able to be adaptable to foreseeable changes in technology, people, and the operational environment. As changes in the technology, pilot population, and operational environment occur, changes to the procedures may become necessary. Less disruption to the operation will occur if the procedures in use are designed so that they can be easily adapted to changes than if new procedures must be developed, trained, and implemented. For instance, procedures that are structured around conceptual steps or functions are more adaptable than procedures that are structured around the specific actions required to operate a given technology.

2.4.2 Practice, Procedures, Policies, and Philosophy—the 4Ps

Procedures provide a powerful means of guiding what pilots do in daily line operations. However, procedures cannot be written for all situations. Not all situations can be anticipated and procedures cannot be written for unanticipated situations. But procedures are not the only means of providing guidance. Policies can be developed that can guide pilots when procedures are unavailable, or when existing procedures are inappropriate for the situation. Furthermore, individual procedures do not exist in isolation, and so policies also assist in the development of a coherent system of procedures. Inconsistencies between procedures can make them difficult to learn and remember, and are likely to breed noncompliance. Beyond policies, the organization's philosophy provides an overall framework for the system of policies and procedures that encourages consistency and provides direction for developing policies and procedures, and guidance for pilots when policies and procedures do not address a given situation. The 4Ps framework provides a systematic way of thinking about the relations between practice, procedures, policies, and philosophy.

1. *Practice.* Practice is what happens on the line. It includes all of the decisions that flight crews make and all of the actions that they take during flight operations. Practice is what is recorded in FOQA and ASAP data, and what is observed during line checks and LOSA. It is the reality of the operation.
2. *Procedures.* It is often believed that all practices should follow prescribed company SOPs. That is not possible. Procedures assume a specific set of conditions, but airline operations are conducted in a dynamic environment. In this environment, not all situations can be anticipated such that a procedure could be written for them. Some situations must be left to situation-specific judgment. Furthermore, some activities for which procedures could be developed can be left to “technique” (personal choice or recommended practice). Prescribing procedures when they are not needed can lead to resentment and to resignation such that when a situation arises for which there is no procedure, people refuse to act on

their own initiative. Furthermore, “overproceduralization” can make it difficult for pilots to learn and remember all of the mandated procedures.

3. *Policies*. While procedures address specific situations and dictate specific actions, policies are put in place to cover a broad range of situations, and to provide guidance for decision-making and action in those cases in which practices must fall outside of existing procedures. Policies are also set to guide and limit general behaviors (e.g., a uniform policy), the way procedures should be conducted (e.g., checklists will be called for by the Captain on the ground, and by the Pilot Flying in the air), or the general ways in which equipment should be used (e.g., automation policy).
4. *Philosophy*. Policies are limited too. The dynamic, and at times unpredictable, nature of the operation may lead a flight crew to find itself in a situation for which no specific procedure exists and for which no broad policy applies. In such cases, the crew’s decisions and actions must be guided by the operator’s overall operational philosophy.

An operational philosophy is a statement of values. It explicitly articulates the operator’s core beliefs. Because values might be in conflict at times (such as safety and on-time performance), the philosophy statement sets a clear order of priorities that must apply under all conditions (e.g., it’s always more important to be safe than to be on time). When the order of priority among conflicting values depends on the operational context, that guidance is set in policies. While the philosophy applies universally, each policy applies to a particular set of conditions.

Selecting the situations for which procedures are necessary must be done judiciously. Specific procedures are required in situations for which there is only one acceptable way to carry out the task. These are situations in which the risk of variability in performance is too large for the operator to accept. For example, during an ILS approach, the aircraft must be on the glide slope beam and on the localizer beam. It is not acceptable to be anywhere else. Thus, the procedure specifies that any substantial deviation must trigger a go-around. At the same time, the crew is given some discretionary space with respect to the landing configuration. It is allowable to land with different flap settings, depending on a number of variables, and it is possible to extend the landing gear at different points in time depending on the energy state of the aircraft. The discretionary space is bounded such that the aircraft must be properly configured by a specific point on the approach. If the aircraft is not properly configured by that point, a go-around must be initiated per procedure. The discretionary space may also be bounded by policy and philosophy. For example, a policy may encourage crews to be efficient and not waste time and fuel by configuring the aircraft far in advance of the landing. But when the crew is uncomfortable with a wet runway and/or crosswind, the fact that a go-around means a late arrival, increased fuel consumption, and other costs may be irrelevant because the operational philosophy clearly places safety above efficiency and above on time performance.

A clearly articulated philosophy provides guidance for the development of policies, which in turn provide guidance for the development of procedures. Procedures dictate the practice in those situations for which there is only one acceptable way to perform the task. Policies guide the practice in those situations that fall outside of procedures. Philosophy guides the practice in those situations that fall outside of policy. When the philosophy, policies, and procedures are clear, coherent, consistent, and comprehensive, practice is well guided and compliance is likely.

2.4.3 Structure of Procedures

Procedures are used to accomplish tasks; e.g., start an engine, taxi, or take off. However, several different tasks may need to be accomplished at the same time or in close temporal proximity. In this case, the steps required to complete the individual tasks may be interleaved, thus combining several *task procedures* into a single superordinate or *phase procedure*. Sometimes the same label is used to refer to both a task and a phase procedure. For example, “taxi procedure” may refer to either the procedures used to taxi the aircraft—the “taxi task procedure”—or to all of the tasks that pilots may need to accomplish while the aircraft is being taxied—the “taxi phase procedure.” The issues involved in sequencing steps between task procedures to create a phase procedure are discussed briefly later in this section. The early part of this section focuses on the structure of task procedures.

A well-designed procedure aids flight crews by specifying a sequence of actions that if followed ensures that the primary task will be carried out in a manner that meets the abovementioned requirements for procedures. In general, good procedures specify 5 elements (not necessarily in this order):

1. *What* the procedure is designed to accomplish.
2. *When* and/or under what conditions the procedure should be executed.
3. *Who* is responsible for executing each step in the procedure.
4. *How*, in detail, the procedure is to be performed.
5. *How* to confirm that the procedure has been accomplished properly.

The procedure developer should be able to specify these elements for each step in the procedure. However, it may be possible to simplify the content of the steps when one or more of these elements are consistent across the steps. For example, if a single crewmember is responsible for completing the entire procedure, it is not necessary to specify at each step that that crewmember will complete the step. Similarly, if each step should be completed immediately following the completion of the previous step, this need not be specified at each step. For example, “Following completion of the after-start procedure and prior to beginning taxi {when}, the Captain {who} will call for the Before Taxi checklist {what}.”

Problems may arise if any of the elements of the procedure are not properly specified. For example, for braking and ground steering to operate properly, it may be necessary for a hydraulic system to be pressurized. Hence, the procedure may specify: “Set hydraulic pump switch to ‘on’ prior to taxi.” However, it may take some time for the system to become pressurized. Simply setting the switch to “on” does not guarantee that there will be sufficient pressure in the system. Indeed, setting the switch to “on” does not even guarantee that the pump is operating. In this case, the proper condition for performing the “taxi” step (hydraulic system pressurized—a verification step; more about types of steps below) was not specified. Furthermore, when adding the verification step to the procedure, the developer may need to specify how the verification should be accomplished (e.g., confirming that there is a particular value on a particular display). In addition, who is to perform each step should be specified. In some cases, there may be a clear advantage to having one member of the crew rather than the other perform a particular step (e.g., the switch is located on one side of the cockpit; the FO is busy programming the FMS).

2.4.3.1 Procedure Goals

Every task procedure is composed of one or more steps in a particular sequence. These steps may serve to further the primary task objective (e.g., start the engines) or to support a secondary goal, typically either to prevent a dangerous or destructive state from occurring or to encourage optimal operation (e.g., safe, efficient, reliable, robust).

Typically, the primary goal of a procedure is to accomplish a particular task or set of tasks in accordance with specified priorities. For example, the goal of the “engine start” procedure is obviously to start the engines. However, company policies may dictate that all procedures should be carried out as quickly, efficiently, and safely as possible. Hence, for this company, the goal of the engine start procedure would be to start the engines as quickly, efficiently, and safely as possible. These secondary goals may require tradeoffs. For example, safety is generally regarded to be more important than speed of execution.

2.4.3.2 Margins, Barriers, and Buffers

To avoid entering unacceptable states, procedure developers can use a combination of procedural margins, barriers, and buffers. By using these tools, procedures can be made resilient and robust. Like physical barriers, procedural barriers are used to prevent undesirable actions. Margins are used to create some space prior to reaching the barrier, and buffers are used to avoid or reduce damage in case both the margins and the barrier are breached.

Stabilized approach criteria are a good example of margins. The go-around gate is the barrier; if the approach does not meet all the criteria by the specified altitude, a go-around must be initiated. The go-around gate is set at an altitude above the runway that provides a buffer such that if a go-around isn't initiated correctly, there is still time to initiate it before contact with the ground.

In general, procedural margins are designed to provide the time, space, and other resources needed to execute actions that will allow crews to avoid damaging states. The limits of margins may be defined by points in time, positions in space, or particular values on other dimensions (e.g., airspeed, temperature, N1/EPR/RPM). For example, an approach procedure may provide a speed margin by allowing the crew to fly $V_{ref} +10/-5$. The procedure requires that the crew take ameliorative actions should the airspeed decrease below V_{ref} . However, if the airspeed decreases below $V_{ref}-5$, the procedural barrier may require that a go-around be executed. The limits of this margin are defined by airspeed and are designed to provide the crew with the time required to recognize and correct a potentially dangerous trend before more drastic actions are required when the barrier is reached. Furthermore, V_{ref} is computed in such a way, that there is still a buffer between $V_{ref}-5$ and the speed at which the stick shaker is activated.

In some cases, margins and barriers may be defined by multiple factors. For example, the approach procedure could require that the crew take ameliorative actions (e.g., increase thrust, decrease pitch) if the airspeed decreases below V_{ref} , but that if the airspeed decreases below $V_{ref}-5$ at any point or the airspeed decreases below V_{ref} when the aircraft is below 200' AGL and not in the landing flare, then a go-around must be executed. Thus, this margin and its associated barrier are defined by both altitude and airspeed. In this case, the barrier prevents entry into a dangerous state not by preventing an action, but by preventing a dangerous condition (low airspeed at low altitude) from occurring.

The limits of margins should be defined with attention to the constraints imposed by technology, human factors, and the operational environment. For example, the aircraft in the above example cannot be allowed to descend below an altitude at an airspeed at which it would be difficult for a typical crew to have the time required to detect, identify, and recover from the problem using the available energy and allowing for the time required for the change in flight path under a wide range of conditions.

Procedural buffers are used to mitigate the effects of undesirable states if these states cannot be avoided otherwise. When margins and barriers are insufficient to reduce the risk of entry into undesirable states to acceptable levels, developers should consider including steps in normal procedures that are designed to lessen or channel the effects of the undesirable states should they occur. These steps can be used to make the applicable non-normal procedures easier to accomplish or more likely to be effective should they be required. For example, a procedure could call for starting the APU to provide standby back-up electrical power and pressurization, or setting-up back-up navigation systems before commencing a challenging approach to reduce the risks should the primary systems fail.

2.4.3.3 Types of Steps

Procedural steps can be classified into different types. Not all types need to appear in every procedure, and their specific sequence depends on the particular procedure. The steps in a procedure can generally be divided into 8 types:

1. *Information gathering.* In many cases, pilots must obtain information before proceeding with a task. These steps may involve reading a display or obtaining information from other sources (e.g., ATIS, dispatch). Information gathering steps specify where to obtain the information and what information to obtain from these sources.
2. *Information processing.* These steps may involve integrating the data gathered from different sources (e.g., conditions from dispatch with performance values from charts or an EFB) and/or performing calculations on the data obtained (e.g., calculating weight and balance, V speeds).
3. *Conditional branching.* In some situations, the appropriate actions to be taken depend on the situation. In these cases, the procedure user may be directed to another procedure or a sub-procedure. These steps are generally written in an “if x then do y” format. For example, “IF functioning was not restored, THEN GO TO Hard Reboot procedure.” This type of step may be more typical of supplemental and non-normal procedures than of normal procedures. For example, “IF deicing is required, THEN GO TO Winter Operation procedures.”
4. *Decision-making.* In some situations, it may not be possible to specify a priori what information is needed, or how the information should be combined to arrive at a course of action. However, it may be possible to provide a list of acceptable actions and a general process for how to decide which action to take. For example, pilots may be told that during preflight planning they should obtain information on the presence of visible moisture, temperatures aloft, pilot reports, and probabilistic icing forecasts to determine whether dangerous icing conditions exist. Based on this information they should take appropriate steps to avoid any dangerous icing areas.

5. *Waiting (timing)*. In many tasks, there are points at which no action can be taken until a specified amount of time passes or a specific event occurs. For example, a procedure may call for a pilot to pause after the landing gear switch is operated until lights illuminate indicating that all of the gear is down and locked. Another procedure might call for the pilot to wait for 30 seconds after activating a pump before operating other equipment to be sure that sufficient time has elapsed for the system to become properly pressurized.
6. *Action*. Many steps direct the pilot to take particular actions. These steps may identify the specific motions required (e.g., move a switch or turn a knob) or they may identify the effect that these actions are intended to have (e.g., switch to battery power, pressurize system, increase pitch). Specifying the particular motions, when done clearly, removes potential ambiguities. Specifying steps in terms of the intended effects allows the same procedures to be used with a greater variety of different, but similar, equipment (e.g., different variants of the same model of aircraft).
7. *Verification*. Some steps may be devoted to ensuring that an action has been taken. For example, a procedure may call for a pilot to verify that a switch is set to a particular position or that a display indicates that a system is operating. Verification steps should be included in a sequence when failure to execute an action would be problematic for later steps in the sequence or later in the flight, as in the case of verifying that the stabilizer trim has been set for takeoff. Verification steps are important safeguards against the effects of interruptions and other distractions.
8. *Validation*. Some steps may be devoted to ensuring that a system remains within desired parameters or alternately that an undesired state does not occur. Validation is distinct from verification. Verification steps ensure only that an action has been taken, not that it has had the desired effect. Depending on the system, verifying that a step has been taken and validating that it has had the desired effect may occur at very different points in time. For example, it takes some time for engine parameters to stabilize following engine start; thus, verification that the engine started can be done as soon as the EGT starts rising, but validation that the engine is running properly can only be done once all the parameters are stable and “in the green.”

2.4.3.4 Phase Procedures

Phase procedures are created by concatenating or interleaving the steps of several task procedures. The interleaving of the steps of task procedures into a phase procedure requires careful assessment of the various technology requirements and their interdependencies, of the operational context within which the procedure is to be executed, and of the typical vulnerabilities of the human who must execute the procedure. In particular, it is critical to minimize the demands for concurrent task management and the demands for deferred actions. People are very vulnerable to interruptions and distractions under both deferred intentions and concurrent tasks. The risk of omitting procedural steps is high under these conditions. For instance, a procedure that mandates that a checklist be performed during taxi creates a task concurrent with taxiing the aircraft. So would a procedure that must be executed during climb upon reaching 10,000'. Because of the sterile cockpit rule, operators may choose to require the crew to make various company reports passing 10,000'; however, in many departure environments that altitude is busy with ATC interactions and potentially conflicting traffic requiring the crew's full attention. Forcing the crew to either manage concurrent tasks or else defer some tasks for a later time increases the risk of errors.

2.4.4 Developing Procedures

This section provides a general approach to the process of developing procedures. This process has 5 steps that are iterated when necessary:

1. Develop a prototype task procedure.
2. Analyze the prototype task procedure.
3. Eliminate conflicts.
4. Develop the phase procedure.
5. Test the phase procedure.

The results of these steps should be documented for future reference should the procedures need to be modified again, for use in training, and for use in seeking approval of the procedures from the FAA/POI Office.

2.4.4.1 Develop a Prototype Task Procedure

Once the goals of the procedure are clear and the constraints and requirements imposed by the technology, humans, and operational environment have been determined from the task analysis, a *prototype* procedure can be created by translating the requirements into a sequence of steps that will accomplish the primary objective of the procedure (e.g., start the engines) and is correct, reliable, robust, and resilient. However, procedure development is an iterative process. The initial draft of a procedure may be modified several times before it is completed. Steps may be added, removed, or modified and sequences may be altered to accomplish secondary goals. For example, the goal of the “engine start” procedure is obviously to start the engines. However, company policies may dictate that all procedures should be carried out quickly, safely, and at the lowest cost possible. In this case, the procedure developer would aim to design a procedure that is correct, reliable, and robust and that can be executed quickly and safely without using resources unnecessarily. Also, the particular phrasing of the procedure can be specified at a later point. The goal of the first round is to develop a prototype procedure.

As noted in the “Structure of Procedures” section above, good procedures specify 5 elements:

1. *What* the procedure is designed to accomplish.
2. *When* and/or under what conditions the procedure should be executed.
3. *Who* is responsible for executing the procedure.
4. *How*, in detail, the procedure is to be performed.
5. *How* to know that the procedure has been accomplished properly.

For the prototype, the procedure outline will generally follow (but not always) these 5 elements in order.

Procedures always involve technological, human, and environmental factors to some extent; this will be reflected in the Task Analysis. In principle, one could start the design process by examining the requirements for the task posed by any one of these factors. Logically, there is no reason to prefer starting with any particular factor as long as all of the factors are considered. However, developers will rarely need to begin from scratch.

Frequently, procedure designers will begin with at least a sketch of the task provided by technical experts. Hence, the procedure design process frequently begins with the consideration of the technological requirements.

For example, to start an engine such as the APU, the engine must be provided with fuel and an ignition source. So, fuel must be brought to the engine. This may require the operation of a fuel pump. The pump and the ignition system will need a source of power to operate. This will need to come from either the ground or an aircraft battery. Hence, without going any further it is clear that several actions are required: e.g., “Set battery power on,” “Set pump on,” “Set ignition on,” “Set engine to start.” Furthermore, some of these actions may need to be performed in a particular sequence.

Similarly, some sequence of actions must be designed to ensure that the area around the engines is clear of ground personnel before the procedure is started. In addition, it may be necessary to receive permission from a ramp or ground control facility to push the aircraft back from the gate before the engines are started. These steps stem from the operational constraints identified in the task analysis. They will need to be interwoven with the steps required to meet the technological requirements as the timing dictates. In this example, a step such as “Verify with ground crew that the area around the engines is clear” may be placed anywhere in the procedure prior to engine start. The timing of other actions by the flight or ground crew may dictate a more precise placement in the sequence.

In designing a task procedure, a particular sequence of steps may be required for the entire procedure. However, it may be possible for some steps to be performed in any order in which case this part of the sequence may be left to the discretion of the pilot. For example, a departure briefing procedure may specify a set of critical elements that must be briefed first in sequence to reduce the likelihood that that part of the briefing will be interrupted (and critical elements potentially skipped). The order in which all other elements are covered may be left for the pilot performing the briefing to determine depending on the particular conditions relevant to the flight.

There are several possible sources from which pieces of procedures can be derived and used in developing a prototype procedure. These include:

Manufacturers. Manufacturers of aircraft and equipment generally provide procedures that are technologically correct. However, the manufacturer cannot foresee all of the possible environments in which the equipment may be used. Manufacturer’s procedures may need to be adapted to take into account the particular operational environment and pilot characteristics.

Other airlines. Other airlines may operate in identical or similar operational environments using the same or similar equipment and have similar operating policies and philosophy. The procedures used by these airlines may provide a useful starting point. In addition, these airlines may have data that can be used to identify potential problems and solutions.

Other fleets within the airline. Other fleets within the airline may operate in similar environments and share the company philosophy and relevant policies. The procedures used by these fleets may provide another useful starting point. However, there may be important differences in operations due to different route structures and the technology used, which will need to be taken into account.

Pilot techniques and workarounds. The techniques and workarounds used by pilots to make existing procedures work can be another useful starting point for developing new procedures and/or revising existing procedures. Workarounds may indicate a problem with the existing procedure, thus identifying a course of action that should not be duplicated in the new procedures. In addition, workarounds may offer a potential solution for a problem. Of course, like any step or sequence of steps, these should be properly evaluated (see below) before being included in the final procedure.

FAA Advisory Circulars and other materials. FAA Advisory Circulars and other materials may provide relevant guidance. Even if the guidance is not directed at operations with identical technology or operational environments as the situation under consideration, the guidance may provide insight and inspire other potential solutions.

2.4.4.2 Analyze the Prototype Procedure

Each step in the proposed new procedure should be scrutinized to uncover any potential conflicts with the limitations of the technology, demands of the operational environment, and limitations of humans. To conduct this analysis, the sequence of steps that comprise the prototype procedure can be entered into a version of the spreadsheet tool used in the task analysis with a column identifying the actions to be taken by each crewmember in chronological order (see Figures 1 and 2). Then potential conflicts at each step can be examined in sequence. Much of the information required for this analysis will be available in the previously developed task analysis (see above).

2.4.4.3 Eliminate Conflicts

If a conflict is detected, the procedure may be modified to reduce or eliminate the problem. In general, one may: (a) alter the timing of individual steps; (b) transfer the responsibility for executing individual steps from one crewmember to another; or (c) alter one or more steps. For example, by using the enhanced task analysis tool presented in Figure 2, one could detect two conflicts in the engine start example discussed previously: given the timeline, the pushback cart and tow bar might be connected to the aircraft (Environment), and the Captain might be communicating with the pushback crew and so distracted from the task of starting the engine (Human). To reduce these conflicts, it is possible to delay engine start until after the pushback crew is released (option A), to transfer the responsibility for starting the engines exclusively to the FO (option B), or to prevent communication with the pushback crew during the engine start sequence (option C). Choosing whom to assign these tasks to should take into account other concurrent tasks. For example, assigning the actions of manipulating switches to the First Officer may be acceptable in view of the human factors problem caused by dividing attention and the risk it may impose on performance.

When it is impossible to implement any alterations or they prove ineffective, procedure developers will need to consider adding steps to the procedure that do not remove the conflict, but only mitigate its effects. In general, these additions will work to either: (a) provide additional support for the task or (b) provide verification steps to catch errors and recovery steps to mitigate the effects of possible errors. For instance, in most situations it is impossible to eliminate all potential interruptions. The procedure designer has no control over many such events, as when ATC might issue a call to the crew, or when a passenger might suffer a medical emergency. However, a procedure could be put in place such that whenever the execution of a checklist is interrupted, the checklist must be re-initiated from its beginning (option A). Alternatively, or additionally, safety critical items could be re-verified. For example, if the procedure for setting the flaps for takeoff might be interrupted (e.g., by

an ATC call), or the step deferred (e.g., due to contaminated taxiway conditions), verifying that the flaps are properly set could be done directly in the Before Taxi checklist, and verified again by a “throttle bump” prior to taking the active runway (option B). In the case of unavoidable deferred tasks, as with setting the flaps when deicing is required, the procedure could require the crew to repeat the complete Before Taxi checklist following the deicing procedure (option A), even though it was already accomplished prior to taxiing to the deicing pad.

When using the tool to analyze the prototype procedure, a column for possible solutions (e.g., techniques or work-arounds) can be added to the spreadsheet such that next to each possible conflict, a possible solution is listed. These solutions then must undergo the same analysis of possible conflicts with the limitations of the technology, demands of the operational environment, and limitations of humans.

2.4.4.4 Develop Phase Procedure

A phase procedure is composed of task procedures placed in a temporal order to ensure that all of the tasks that must be performed during a phase of flight are properly completed. The task procedures may be concatenated or interwoven. Whenever the steps of the task procedures that comprise the phase procedure are interwoven, there is an increased risk of cross-task interference. However, interweaving the task procedures may be necessary to accomplish all of the tasks that must be completed. For example, during the approach phase, the flight crew must both fly the approach and configure the aircraft for landing.

Whenever multiple tasks must be completed together, the procedure developer must ensure that the steps required to perform one task do not interfere with the performance of the other tasks. This is the primary concern that distinguishes the process of developing phase procedures from the process of developing task procedures. In developing task procedures, the developer creates steps that, when properly sequenced, accomplish the task and do not violate any of the technological, human factors, or operational environment constraints. However, when tasks are interwoven it is possible that the new arrangement of actions can create conflicts between these factors that were not previously present. Hence, the same process described above of evaluating the sequence of steps for conflicts must be accomplished, and if a conflict is detected, the procedure again must be modified to reduce or eliminate the problem. As with task procedures, when a conflict is discovered in a phase procedure the developer may: a) alter the timing of individual steps or entire tasks within the phase, b) transfer the responsibility for executing individual steps or entire tasks from one crewmember to another, or c) alter one or more steps in the individual task procedures.

And as with the task procedures, when it is impossible to implement any of these alterations or they prove ineffective, one may be forced to add steps to the phase procedure that do not remove the conflict, but only mitigate its effects. In general, these modifications will work to either: (a) provide additional support for one or more of the tasks included in the phase procedure or (b) provide verification steps (e.g., checklist items) to catch and recover from errors.

For example, under low-visibility weather conditions there are often delays, which provide an opportunity for substantial fuel savings by not running all engines during the long taxi time. However, when trying to save fuel by taxiing for departure on a single engine, a procedure must be developed to start the other engine(s) prior to take off. Attempting to start an engine while taxiing carries particular risks. To mitigate such risks, single-engine taxi procedures may add a step, calling

for a confirmation of “all engine indications in the green” prior to taking the runway. The conflict between the demands of the taxi procedure and the engine start procedure are still there, but some of the effects of that conflict are mitigated by the added step.

Using the Aviation Task Analysis Tool in procedure development. At this point in the procedure development process, the actions required to fulfill the mission must be identified and allocated to the crewmembers while taking into account the constraints imposed by the requirements of the technology, the demands of the operational environment, and the limitations of the human pilots. The Aviation Task Analysis Tool can be adapted for this purpose. In Figure 4, the information obtained from the task analysis is displayed (shaded columns) together with several additional columns.

| Time | Captain | | | | | First Officer | | | | | Comments |
|------|------------------|-------------------------|---------------|------------|---------------|---------------|------------|---------------|-------------------------|------------------|----------|
| | Potential Errors | Operational Environment | Human Factors | Technology | Step/Activity | Step/Activity | Technology | Human Factors | Operational Environment | Potential Errors | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

Figure 4. Aviation Task Analysis Tool.

Time runs along the vertical axis. The left-hand half of the table is focused on the Captain; the right-hand side is focused on the First Officer. Depending on the operation, these headers could be used to identify the Pilot Flying and Pilot Monitoring instead. Each step in the procedure is noted on the center columns marked “Step/Activity.” Steps performed by the Captain are noted on the left, while steps performed by the First Officer are noted on the right. Then the technological, human, and environmental factors that influence each step are noted on the left or right halves of the table, depending on which crewmember is affected. Finally, potential problems and other comments are listed. Multiple simultaneous activities can be tracked by noting when each step starts and stops on a different line.

This structure can be used at different levels of granularity. The more specific the action list, the finer grain the analysis and the more precise the result. Thus, if the action listed is “perform preflight flow,” the level of granularity will be very different from the level of granularity available if every item on that flow is listed separately. It may be possible to determine the most useful level of granularity in advance. However, usually it’s easier to start with the finest grain first and later combine rows if the fine-grain analysis proves to be too detailed, than to start with a coarse grain and later realize that a finer grain analysis is needed.

For example, to determine where to place items that must be checked prior to takeoff (e.g., flap setting), the procedure developer can examine the period between engine start⁵ and arrival at the runway threshold. One option would be to place these items on a taxi checklist. However, during this period there would be two potential conflicts: (1) during taxi, both pilots need to attend to signs, taxiway and runway markings, ground vehicles, and other aircraft (operational demand for both pilots) and they cannot do so effectively (human limitation) while completing the checklist, and (2) ATC may issue additional instructions (operational demand) that could interrupt the checklist and create a prospective memory problem, or be missed because the crew is focused on the checklist procedure (human limitations). The procedure developer could then “slide” the checklist in the tool to different time periods before or after taxi to find a point during which conflicts are minimized.

2.4.4.5 Test Procedure

The analysis of the proposed procedure provides the basis for the first round of changes to the prototype procedure. Once it is clear that the prototype procedure has properly addressed all the concerns raised in the analytical process and that all possible conflicts have been addressed, the phase procedure should be tested for *feasibility* and *practicality*.

Feasibility testing. Feasibility testing may be performed by pilots involved in the development of the procedure. These pilots should attempt to enact the phase of flight in which the procedure is to be used under a variety of conditions. These conditions should include a variety of routine challenges—such as ATC calls, weather issues, airport constraints, calls from the cabin—and non-routine challenges that might be relevant. *Feasibility* testing is aimed at determining whether the procedure is sufficiently reliable and robust under the operational conditions that will be encountered. This testing too is an iterative process: any time a problem is identified, the procedure must be revised to address that problem, and then tested again to make sure the revision did not create new problems. Initially, this testing may be performed in a procedure trainer or even as “armchair flying.” However, the procedure should eventually be tested in a fully functional flight simulator.

Practicality testing. If the procedure passes feasibility testing by the procedure developers, the process should be repeated in a full mission flight simulator using line pilots not involved in the development process. Again, this testing should include a variety of routine and non-routine challenges. These pilots should have received only the training that will be made available to all line pilots once the procedures have been approved. The purpose of this practicality testing is to determine whether it is indeed practical to implement the procedures across the fleet or the airline.

If the procedure passes the feasibility testing but not the practicality testing it may be possible to improve performance by modifying either the procedure or the training. For example, pilots familiar with the procedure may have developed techniques that allow them to perform the procedure appropriately under conditions that confound line pilots. It may be possible to incorporate these techniques into the procedures. Alternatively, it may be necessary to provide line pilots with additional or different training that allows them to build the procedural knowledge that the pilots involved in the development of the procedures possess.

⁵ This is a technology limitation. Setting flaps requires hydraulic pressure, which is only available after the engines are started.

2.4.5 Developing Checklists

Checklists are a special type of procedure. Checklists are often considered the prototypical example of procedures. They are often the form into which extended procedures are distilled, and often the most common and most frequent form through which people interact with formal procedures. On the flight deck, checklists are important tools for making sure that the work is done correctly.

This section is focused on checklists because of their special status among phase procedures. Like any procedure, once a prototype checklist has been developed, it must be subjected to the analysis step using the same tools and methodology described above. All potential conflicts must be addressed, and the checklist must be thoroughly tested for feasibility and practicality. In addition to the design of the list itself, the checklist procedure—the manner in which the checklist is to be executed—must be designed, analyzed for possible conflicts, and tested.

Although all airplanes come with the manufacturer's checklist, the manufacturer is only required to furnish operating procedures (14CFR 25.1585) in the form of an Airplane Flight Manual (14CFR 25.1581). Thus, the true responsibility for the checklist lies with the airline (14CFR 121.315), not with the manufacturer. Manufacturers know a great deal about the technology and the engineering requirements for operating the aircraft, but the manufacturer is not an operator and thus has only indirect knowledge of the operational environment and the particular skills, training, and experience of an airline's pilots. Therefore, operators may need to modify manufacturers' checklists to fully meet their own needs.

Because it is unlikely that an operator would have to design the full set of flight checklists from scratch, it is assumed here that the task at hand involves the revision of an existing checklist, or the creation of a new checklist to address a particular kind of operation (e.g., RNP), or a particular new piece of equipment (e.g., a HUD). Moreover, given the extensive experience in the industry with checklists, even manufacturers that produce a new model of an aircraft do not start the checklist design as if it's the very first time a cockpit checklist has to be designed. Thus, a general discussion of normal checklists and their phase-of-flight organization is not included here.

In the most general sense, any list can be construed as a "checklist," especially any list in which items get "checked off" as they are accomplished. Some such lists are "do-lists." That is, the items on the list describe actions, and the person executing the list looks at an item, performs it, then looks at the next item and performs it, and so on until all items are done. On the flight deck, abnormal and emergency procedures are often performed using a checklist as a do-list. Such a do-list must contain all the actions to be performed. For most normal procedures on the flight deck, the checklist is used to check and verify that actions that should have already been done were indeed done correctly. This procedure assumes that a "flow" (i.e., a sequence of actions done from memory to configure the aircraft and its systems) was conducted, and that the flow is followed by a checklist containing selected items that can be used to confirm that the entire flow was performed correctly.

Designing good checklists and good checklist procedures involves considering and determining the following 11 aspects:

1. *Consistency.* The checklist, as an integral part of the system of procedures, must be consistent with that system, which in turn must be consistent with relevant policies, which in turn must be consistent with the overall operational philosophy. In other words, when it comes to designing a checklist, even when only tasked with assessing the

introduction of a single checklist item into an existing checklist, the company's operational philosophy and the policies which are relevant to procedures and to checklists should first be reviewed to ensure consistency. Questions about which items should be on a checklist, how to accommodate different types of operations, and how lists should be standardized should not be resolved on a checklist-by-checklist basis. For consistency, these issues must be addressed in a checklist policy and applied uniformly.

2. *Type of list and manner of execution.* A do-list is often executed in a "read-and-do" fashion, whereas a check-list is often executed in a "challenge-response" fashion. Either type list and either manner of execution can be performed by a single pilot or by both crew members. When the checklist is performed by a single pilot, it can either be performed silently, or aloud. As always, there are trade-offs that must be considered in making these choices. A do-list is usually longer than a check-list, and may be significantly longer. Performing the checklist silently, leaves the other pilot out of the loop and forgoes an important safety-mechanism built into the checklist procedure. Involving both crewmembers in the performance of the checklist contributes to the coordination between them, and to the creation of a shared mental model. However, in non-normal situations and under time pressure, it might be better to divide the workload such that one pilot is focused on flying the aircraft and is perhaps involved in coordinating with ATC, the cabin, and dispatch, while the other pilot performs the checklist. Also, because normal operations are conducted very often and entail many repetitions, flows can be trusted to memory such that the checklist can be used as a check-list. Because non-normal procedures are performed very rarely (usually only during training) and because of the potential criticality of their execution, nothing should be trusted to memory; the checklist must be used as a do-list.
3. *Timing.* During normal operations, most checklists are designed to ascertain that the aircraft is properly configured and ready for the next phase of flight. Hence, checklist titles often start with the word "before," as in "before engine start," "before takeoff," and "before landing." Also, if the list is used as a check-list, the checklist procedure should be initiated after the preparation of the aircraft for the next phase is completed.

Given the criticality of the checklist procedure, the crew's ability to pay full attention to its execution is crucial. The timing of the checklist must be such that it would minimize the risk of interruptions, distractions, and concurrent tasks. For example, a "Taxi Checklist" that is to be accomplished during taxi might appear as an efficient use of crew time, but it creates a high risk situation because the crew cannot pay full attention to both the taxi and the checklist. Thus, to determine an appropriate time for the checklist, a thorough understanding of the operational context within which the checklist will be used is necessary. This understanding can be used to identify possible "pause points," short time periods when other activities can be suspended long enough to execute the checklist without interruption.

If the analysis of the operational environment suggests that there may not be enough time for a reasonably paced and deliberate execution of the checklist, it might be possible to re-design the checklist such that some of the items from that list can be performed at a different time, and only the absolutely necessary items left for that short pause point. For example, most of the actions necessary to configure the aircraft for takeoff can be done prior to taxi. The time point at which the pushback crew is released, the engines are running, and the parking brake is still set is completely under the control of the crew.

This is an excellent pause point; even if the flight is delayed, or other aircraft are queuing for the ramp, the operation is under the control of the flight crew. It is much harder to pause the operation at the hold-short line. Thus, it is better to have a long Before Taxi checklist and a very short Before Takeoff Checklist than the other way around.

4. *Roles*. The role of providing the right cue at the right time for initiating the checklist is always assigned to one of the two pilots—usually, the Captain on the ground and the Pilot Flying in the air. The cue comes in the form of a verbal call (e.g., “Before Start checklist!”), and serves to prompt the other pilot to retrieve the checklist (i.e., if using a paper checklist, to pull it out from its storage position; if using an electronic checklist to scroll to or bring up the correct screen). If the checklist is for normal operations, is a check-list rather than a do-list, and involves both crew members in a challenge-response interaction, both pilots would then be expected to direct their attention to the checklist task. The pilot responsible for leading the checklist begins by calling out (or “challenging”) the first item on the list. The other pilot determines whether the item has been performed correctly and provides the relevant response (see discussion of phraseology below). There are several variations on the theme of the challenge-response method. Following the response of the responding pilot, the challenging pilot may: (1) immediately go on to challenge the next item, or (2) independently verify the state of the item before going on to the next item. The verification may or may not involve specific gestures such as pointing to the relevant switch, lever, or indication. If the item is independently verified, the challenging pilot may or may not provide a verbal response.

Given the high tempo of most operations and the large number of repetitions of these procedures, there is always the risk that people may go through the words or through the motions without actually paying full attention to the process. Thus, it is best to place the checklist procedure at an appropriate time, assign the roles, and design a procedure that would best support a well-paced and deliberate execution of the checklist.

5. *Initiation anchor*. The initiation of a checklist is best anchored to a clear cue that cannot be easily removed or obstructed, such as the occurrence of a particular event (e.g., arrival at a point 2000 feet prior to the hold-short line may cue the initiation of the Before Takeoff checklist). Sometimes, the initiation of a checklist is left open, constrained only by a time window (e.g., the Taxi checklist is to be completed anytime during taxi) and/or acceptable circumstances (e.g., the checklist is to be completed when both pilots are free of other duties). In these cases, pilots may use internal or external cockpit cues to help them try to remember to initiate the checklist at the correct time. However, without clear anchors, there is a high risk that checklists will not be initiated at the appropriate time. Pilots may then rush through the checklist, omit parts of the checklist, or fail to perform the checklist altogether. The importance of having clear and reliable external cues to trigger the initiation of the checklist procedure at the right time cannot be overemphasized.
6. *Completion signal*. The checklist completion signal enhances situation awareness and crew coordination by providing tangible evidence that the checklist has been performed in its entirety. It also may cue the next procedure or other activities. The most common completion cue is a verbal annunciation (e.g., “Before Taxi checklist complete!”) made by the pilot who is responsible for leading the execution of the checklist. The completion call may be written out as the last line item, or centered under each checklist. When the completion call is not explicitly listed on the checklist, pilots must rely on memory or

personal technique for signaling the completion of a checklist. A common technique is to rely on the gesture of returning the checklist card to its storage place on top of the glareshield, or by making a similar gesture in the case of an electronic checklist.

However, such gestures can be easily missed by the other pilot, and the attempt to create a shared situation awareness then fails. A failure to provide a clear checklist completion signal removes a layer of redundancy and increases the risk of omissions.

7. *Format.* Checklists may be presented in paper or electronic formats. The particular format a checklist might take has more to do with the available technology and financial resources than with the intended content of the list itself.

7a. *Paper.* With paper checklists, the entire set of checklists required for flight may be printed on a paper card, which is typically laminated. It is placed in a holder, often on the glareshield or on the side of the center pedestal, from which it is retrieved and held in the pilot's hand when he or she wants to execute one of the checklists listed on it. Paper checklists are easy to handle both operationally during flight and administratively when changes have to be made. The mere act of holding a paper checklist card in one's hand provides a cue for the execution of the checklist. However, the paper checklist also presents disadvantages, the main one being the lack of a pointer to mark unaccomplished items, or the point at which a checklist is interrupted. The need to hold the checklist may also interfere with performing other actions.

7b. *Electronic.* ECLs can vary from the electronic equivalent of the paper card displayed on a tablet computer of some kind (or even a cellphone), all the way to an integrated checklist that can be displayed on any of the screens available in the cockpit. Fully integrated checklists are connected with aircraft systems as well as with the aircraft GPS and FMS. These checklists can be sensitive to the aircraft's state and can be programmed to display automatically at the appropriate times. An operator's ability to modify the ECL depends on the particular ECL (e.g., an operator's produced Class 1 EFB vs. an integrated ECL), the aircraft model, and the specific arrangements the operator might have with the manufacturer.

8. *Content.* Assuming that the list is used as a check-list rather than a do-list, and that a flow is accomplished prior to the initiation of the checklist procedure, the checklist itself need only contain two types of items: critical items and representative items.

8a. *Critical items.* Critical items are those items whose omission would have a direct and severe adverse impact on the safety of the operation; for instance, setting the flaps for takeoff.

8b. *Representative items.* Representative items are selected items that represent a whole subset of flow actions such that if the selected item was performed correctly, the whole subset must have also been performed correctly. For instance, if all engine indications are in the green, the whole engine start sequence must have been done correctly. Therefore, checking the engine indications can serve as a representative item for the engine start sequence.

A single item can be both critical and representative. For instance, confirming the correct Vspeeds before takeoff represents a long sequence of FMC programming entries and ensures a safe takeoff and obstacle clearance during the initial climb.

Sometimes there might be pressure to add an item to the checklist because that item was omitted in the past and the omission led to an incident or an accident. In such cases, it is critical to carefully analyze the true reasons for the omission. It is often the case that the real problem resides elsewhere. Furthermore, although it may seem that repeating an item provides greater reliability, when people have in their mind the impression that an action has already been done, calling for it again is not likely to change that impression. Thus, repeating an item, even under a different task-checklist (e.g., calling for flaps on the Before Taxi checklist and again on the Before Takeoff checklist), may not be an effective mitigation strategy. A more effective approach than a simple repetition of a line item is the inclusion of a different check that serves the same purpose. For instance, setting the flaps for takeoff can be part of the After Start flow and confirmed by a line item on the Before Taxi checklist, and then confirmed again by a quick advancement and retraction of the throttle/thrust lever during the Before Takeoff checklist, using the takeoff configuration warning horn to reveal to the crew if the flaps have not been set for takeoff. However, technologically based hardware solutions are not a fail-proof cure-all. For example, the takeoff configuration warning system has failed in the past (e.g., NWA 255, SpanAir 5022), and the throttles may require more than a gentle nudge or even a quick forward and back movement to activate the warning system. Also, such a test cannot reveal cases in which the flaps are extended, but to a different setting than the one required for the specific takeoff (which is also a problem with integrated ECLs).

9. *Item order.* If the flow preceding the checklist is carefully designed to take advantage of the physical layout of switches, displays and indicators in the cockpit (e.g., going from left to right, and/or from top to bottom), to account for the inherent dependencies between the systems involved (e.g., electrical system first and only then fuel heat), and is built to support human memory (e.g., chunking or clustering related activities together), and if the checklist is indeed short, then the internal order of the items on the list can simply mirror the sequence of the flow, or of the operation. Such order aids in learning, increases ease of use, and avoids dissonance given the flow habits.

Another possible ordering consideration is item priority. Often, the checklist is called for when the workload is low and the probability of interruption is also low. So the first few line items of the checklist would have a relatively low probability of being omitted due to an interruption. The probability of interruptions and distractions increases with checklist length and the time it takes to execute it. Thus, even though checklists mainly contain critical items, these could be prioritized, and those with higher importance placed first on the checklist.

10. *Length.* A checklist should be as long as it needs to be, and as short as possible. An airline may choose to set different checklist length policies, depending on the type of operation involved. For instance, there are several differences between long-haul and short-haul operations with respect to checklist use. Pilots who fly short flight segments perform the flight checklists multiple times per day, and many times on a typical trip rotation. Therefore, a requirement to conduct a long and detailed checklist for each flight phase may lead some to deviate from prescribed procedures. In such cases, the flight crews often check only what they perceive to be the critical items (“killer items” as some call them). Pilots who are required to use long checklists often express concern about poor checklist discipline in short-haul operations. In long-haul operations, the reverse occurs. Pilots who fly long routes usually perform the flight checklists only once a day,

and very few times, often only twice, per trip rotation. Furthermore, pilots who fly long haul operations find themselves flying very few trips per month, and so express little resistance to a long and detailed checklist. In fact, these pilots may welcome the support it offers. Thus, the airline may choose a policy of short checklists for their short-haul operation and of longer and more detailed checklists for their long-haul operation.

11. *Phraseology.* As with the phrasing of all procedures, the challenge part of a checklist item is best phrased to mirror the label used in the cockpit for the corresponding switch, lever, indicator, or system. The response part is best phrased in terms of the actual system state, switch or lever position, or the specific parameter value.

The generic responses of “set,” “checked,” or “as required” may not be very informative and do not provide as good an opportunity to confirm correct action as the actual indication. Compare, for instance, the response to the challenge “Flaps!” with “set” vs. with “position fifteen, indicated fifteen.” The second response provides both the flap handle position and the flap indicator indication, confirming that not only the lever has been placed in the correct position, but that the intended effect has also occurred, and thus providing a complete and accurate description of the state of the flaps. Such an item can appear on the checklist with the call “flaps” followed by “position _____, indicated _____” to enable the responding crewmember to provide the specific values. Similarly, the response to the call “landing gear” prior to landing should be “down, locked, 3 greens” communicating the handle position (down) gear status (locked) and the down and locked confirmation lights (3 greens). When indications must be compared, for instance, the altimeter settings of the two pilots’ instruments must be identical, the response to the call for the Altimeters could be “30.01 (observed value), set, cross-checked.” That response communicates the required altimeter setting (per ATIS or ATC), the fact that it is set correctly, and the fact that three different instruments, the Captain’s the First Officer’s and the standby all show the same setting. Similarly, printing “as required” as a response on the checklist isn’t helpful. The response should be the system state. For instance, anti ice may or may not be required. The checklist could list anti ice, and leave the response open for the crewmember to say whether it’s ON or OFF. It’s possible to elaborate the response: “is/not required and is ON/OFF.” Alternatively, it’s possible to list the line item as “if anti ice is required, anti ice... ON.” Either way, “as required” is not an appropriate response on the checklist. Clearly stating the switch position, the action taken, or the system state provides all the information needed, nothing is extraneous, and there is no ambiguity about it.

2.5 Step 5: Writing Procedures

Once procedures are developed, they must be communicated and trained effectively. In this section, guidelines for the written communication of procedures are presented. These guidelines may apply differently, depending on whether the writing is of detailed procedures or of checklists, and on whether the writing is for normal or for non-normal procedures/checklists.

2.5.1 General Guidelines

1. *Include only the information needed to understand how to execute the procedure.* It is important to communicate the rationale underlying procedures as well as the rationale for not implementing other possible solutions. It is also useful to communicate the procedure development process to

establish its validity and effectiveness. However, this information should be provided in a separate training manual or other documents.

2. *Include supplemental detail only when necessary.* Avoid clutter. When the addition of supplemental information is necessary, separate the supplemental information from the presentation of the steps in the procedure (e.g., separated by white space from the list of steps, or in a separate column).
3. *Follow the rules of grammar.* Ungrammatical sentences are difficult to read and often misunderstood.
4. *Use short sentences with simple sentence structure.* Break long sentences into short sentences.
5. *Write steps as imperatives (commands).*
6. *Write steps as positive commands.* Avoid negatives when possible. Negative statements are difficult to read. If the negative is missed, the meaning of the sentence will be misunderstood. When negatives are required, clearly specify what is being negated.
7. *Use active verbs.* Sentences with active verbs are easier to read and less likely to be misunderstood than sentences using passive verb forms (e.g., “Do X” rather than “X should be done”).
8. *Use standard punctuation correctly.* Use colons to indicate that a list will follow. Separate items in lists with commas when necessary. Semicolons conjoin what would be separate sentences. Because sentences in procedures should be as short as possible, semicolons are rarely required.

2.5.2 Organization

1. *General organization.* Organize procedures as simply as possible by the task to be performed. Normal procedures are typically organized in sequence by phase of flight. When applicable, non-normal procedures should be organized by the triggering condition (e.g., “Smoke in the cockpit” rather than the potentially related system).
2. *Hierarchies.* Use a simple numbering system for steps within a procedure to assist pilots in maintaining their place in the procedure. Excessively detailed hierarchies should be avoided. Use headers when necessary to distinguish major sections of multifaceted procedures. Headers should provide useful cues to the purpose of the section of the procedure they distinguish.
3. *Lists.* Steps may require that the pilots perform several actions or check several different indications. Present these components on separate lines in an indented numbered or bulleted list rather than in the body of the text.
4. *References.* Avoid references to other procedures or appendices whenever possible.
5. *Memory items.* Avoid memory items whenever possible. If the procedure must include memory items, they should be clearly identified.

6. *Indices*. Provide an index for every procedure manual. In designing the index, keep in mind that pilots may adopt different index search strategies depending on their background and the situation. If a procedure is likely to be identified in more than one way (e.g., if there are multiple indications), include all likely referents in the index.

2.5.3 Vocabulary

1. *Use words consistently*. Word use should be simple and consistent throughout the SOPs. If possible, avoid creating new terms. Use words in their common English sense unless they have a widely accepted aviation specific meaning. Match flightdeck nomenclature.
2. *Avoid using words with multiple common meanings whenever possible* (e.g., use “correct” rather than “right”). Avoid using the same words as both nouns and verbs (e.g., display, position); if a word is to be used that could be a noun or a verb, choose one usage and apply it consistently (e.g., move the switch into the ON position vs. position the switch to ON).
3. *Use short simple words*. Avoid long words whenever a shorter word will do.
4. *Use abbreviations carefully*. Only use abbreviations that are defined and commonly used in the industry (e.g., VNAV, Vref, MCP/FCU/FCP), and avoid creating new abbreviations whenever possible.
5. *Avoid using words that could be easily confused*. In context, words that are similar in physical form or sound can be confused easily. For example, “descend, two four zero zero” (meaning 2,400 feet) was fatally confused with “descend to four zero zero” (meaning 400 feet).

2.5.4 Numbers

1. *Use Arabic numbers*. Arabic numbers (e.g., 0, 1, 2) are easier to read than numbers that are spelled-out (e.g., one, two). However, use spelled-out numbers for references to the number of items or when two or more different values must be presented in close proximity to other numbers (e.g., use “one 10 kg weight,” rather than “1 10 kg weight”).
2. *Include units of measurement* (e.g., feet, pounds, miles).
3. *Do not specify numbers in greater precision than is necessary, or than can be read from instruments*.
4. *Avoid requiring pilots to perform mental calculations whenever possible*. For example, use ranges (e.g., 10-20 KIAS) rather than error bands (e.g., 15 ± 5 KIAS).

2.5.5 Format

In determining how to format procedures, the purpose, mode, and conditions under which the displayed procedures will be used must be considered. Presentations of procedures that are meant to be used on the ground at leisure in printed form may use a different format from procedures that will be read from a tablet computer in a vibrating cockpit at night under time pressure. The recommendations presented here should not be taken as a substitute for evaluating the presentation under conditions approximating those under which the procedure display might be needed.

1. *Type size*. Use a type size that is large enough to be easily read under all conditions likely to be encountered. In general, a 14–20 point laser printed font⁶ is adequate for cockpit conditions. However, this should be tested under all potential operational conditions.
2. *Line spacing*. Place sufficient space between lines of text. Using 25% to 33% of the font size between lines (e.g., 3–5 points space between lines using 14 point font) will make the text easier to read than if there was less space between the lines.
3. *Font*. Avoid unusual or ornate fonts. The readability of specific fonts depends on many characteristics (e.g., openness of letters, inter-character spacing, etc.). Evidence for the greater readability of serif fonts (e.g., Times) or sans serif fonts (e.g., Helvetica) over the other is inconclusive.
4. *Case*. Use standard capitalization rules. Text in all capital letters is harder to read than text in lower case. Use all capitals very sparingly and only for meaningful emphasis (e.g., WARNING) or to represent labels that are commonly encountered in capitals (e.g., FLCH).
5. *Grouping*. Use visual techniques (e.g., white space created by extra lines, indentation) to delineate grouping of steps, lists, and the components of logic statements.
6. *Justification*. Use left aligned text. Paragraphs of text should not be right and left justified so as to produce aligned right and left edges. Justification introduces spaces between letters and/or words that make the text harder to read.
7. *Line length*. Traditionally, checklists have been formatted to resemble an index or table of contents with corresponding components (e.g., Challenge...Response) left and right justified and joined with dots or lines. Avoid excessively large gaps between the components. The wider the gap, the greater the chance that the pilot will make a mistake due to perceptual misalignment— inadvertently skipping to the next line.

2.5.6 Place-keeping

1. *Title*. Clearly identify the procedure by title (e.g., “Before Start”) and the objective of the procedure when it is not obvious from the title.
2. *New lines*. Begin each step in a procedure, each element in a logic statement, and each item in a multiple item list on a separate line.
3. *Bullets and numbering*. Use numbers, bullets, and/or lines to indicate the beginning of each step. Using numbered lines can reduce navigation and place-keeping errors. If the procedure is interrupted, the pilot may be able to recall the last numbered step completed. Numbered steps also

⁶ Point size is a convenient but inaccurate measure of letter size. Letters with the same point size can be substantially different sizes depending on the font. More accurate measures of letter size such as “x-height,” the distance between the baseline of a line of type and tops of the main body of lower case letters (e.g., “x”) exist but are not in common use. Furthermore, readability depends on more than just letter size (see other topics in this list).

facilitate navigation between procedures when it is necessary to “GO TO” a step within a procedure.

4. *Continuation*. Clearly specify if a procedure continues onto another page (e.g., “Continues on Next Page”).
5. *End*. Clearly mark the end of a procedure with a standard symbol and/or wording (e.g., “Checklist Complete”).

2.5.7 Emphasis

Emphasize: cautions and warnings (e.g., CAUTION, WARNING), negations (e.g., NOT), logic expressions (e.g., IF, THEN), and important notes (e.g., NOTE). Techniques for calling attention to certain words or phrases should be used sparingly and consistently. Overuse of emphasis reduces its effectiveness and makes the procedure hard to read.

1. *Typographical*. Typographical emphasis techniques include bolding, italicizing, underlining, and using words in all capital letters.
2. *Graphical*. Graphical emphasis techniques include framing, shading, coloring, and the use of standard symbols.
3. *Spatial*. Spatial techniques for conveying emphasis include using white space to group text and reserving places on the page or screen for selected types of messages.
4. *Verbal*. Verbal emphasis may be conveyed by using reserved words; e.g., Important, Note, Caution, and Warning.

2.5.8 Conditional Steps

In many procedures, some steps should be executed only when specified conditions occur. These conditional statements are a frequent source of confusion, particularly for novices and with rarely used procedures. However, this problem can be alleviated by keeping the statements well structured, clearly phrased, and as short as possible.

1. Conditional statements should present all of the conditions clearly so that the correct choice is easy to identify.
2. The steps that are associated with each condition should be grouped clearly. The end of a block of steps should be clearly identified and the action or procedure to be performed after completion of the block should be clearly specified. If there are embedded choices, then these subsidiary conditions also should be clearly delineated and the associated steps grouped clearly.
3. Conditions should always precede actions. Actions that are irreversible should be identified in the condition preceding the action.
4. Conditional words should be emphasized.

5. Conditional statements may begin with one of the following words:

- **IF** – use to indicate a condition that may or may not happen.
- **WHEN** – use to indicate a condition that must be met before an action is taken and that condition is very likely to occur (e.g., “WHEN pressure reaches 120 psi THEN put gear down.”)
- **THEN** – use to identify actions that should be taken when the specified condition occurs
- **AND** – use to combine two conditions that must be met before the action is taken
- **OR** – use to indicate that one or more of several conditions must be met before the action is taken

However, alternative formats may be used as long as they are used consistently and the intention is clear. For example:

```
IF light x is lit
    THEN open valve y
IF light x is NOT lit
    THEN open valve z
```

may be expressed as:

CHOOSE one:

```
| Light x is illuminated
|   • Open valve y
| Light x is extinguished
|   • Open valve z
```

6. *Complex conditional statements.* Avoid using combinations of AND and OR whenever possible. In general, use separate steps instead. In particularly complex cases, a flow chart or logic table may be preferable.

7. *Waiting, continuous actions, repeated actions.* In some cases, an action must be continued or repeated until some condition occurs. In these cases, specify: what actions are to be repeated, the conditions under which those actions should be stopped, and whether the remaining steps in the procedure can be continued in the meantime. For example: “Hold button depressed UNTIL pressure reaches 120 psi, THEN GOTO step 5 in this procedure.”

2.5.9 Cross-references

1. *Avoid cross-references to other procedures whenever possible.* In most cases, a “Go-in, Stay-in” strategy should be used whereby all necessary steps for completing a procedure are included in that procedure. However, in some cases this may prove impractical.

2. *Explicit reference.* When used, cross-references should be explicit and use consistent wording. For example:

```
GO TO [referred procedure name] Step [step #] on Page [page #]
```

3. *Returning.* As noted above, in general a “Go-in, Stay-in” strategy should be used whereby all necessary steps for completing a procedure are included in that procedure. If a cross-reference must be used, then the steps in the referring procedure that must still be performed should be

included in the cross-referenced procedure. However, in some cases this may be impractical and once selected steps within the referred procedure are completed, the pilot should return to the original procedure. In these cases, a step should be included in the referred procedure that explicitly instructs the pilot to return to the previous procedure: (e.g., RETURN TO [step #] IN [original procedure]). When the previous procedure should not be continued, this should be stated explicitly in both the referring and referred procedures.

4. *Version control.* Version control is always important. When references to other procedures are required, version control becomes more difficult. Changes made to either the referring or referred procedures could affect the execution of the included steps.

2.5.10 Flow Charts and Logic Tables

When a procedure contains multiple decision points (e.g., diagnostic procedures), it may be preferable to use a flow chart or logic table instead of a complex set of conditional statements. However, the branches in complex flow charts with multiple lines can be confused. Flow charts should not be used when only a simple sequence of actions is required. To decrease the likelihood of reading errors, the amount of text included in flow charts should be minimized. Limit the text to actions, decision points, and diagnostic criteria.

1. *Symbols.* Use flow chart symbols consistently.
2. *Layout.* Using white space, arrange flow charts into apparent rows and columns with a clear consistent direction.
3. *Combining branches.* When multiple branches lead to the same point in the flow chart, they should be combined as soon as possible.
4. *Crossing branches.* Avoid crossing flow lines whenever possible. To avoid crossings, repeat steps in separate branches. If a crossing cannot be avoided, use a bridge in the flow line (see Figure 5).

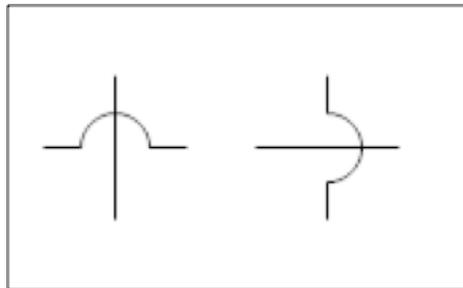


Figure 5. A bridge over crossing lines in a flow chart.

2.5.11 Warnings and Cautions

Warnings and cautions alert procedure users to hazards that could do serious harm to people or equipment. They should be used in addition to (not instead of) steps describing the actions that should be taken and they should be used sparingly. Overuse of warnings will decrease their effectiveness. Often “warning” and “caution” are used as synonyms. However, warnings are sometimes used to refer to hazards to people whereas cautions are used for hazards to equipment.

Sometimes “warning” is used to convey a more urgent or critical matter than “caution.” The meaning of these words should be defined and used consistently.

1. *Use negative imperative active voice.* For example, “CAUTION: Do not attempt manual restart if automatic start fails. Starter may be damaged.”
2. *Components of warnings and cautions.* Each warning or caution should identify: a single hazard, the consequences of the hazard, and any critical time constraints. Actions should not appear in warnings or cautions.
3. *Placement.* Warnings and cautions should be placed on the same page and before the steps to which they apply. Keep procedural steps separated from warnings and cautions graphically.

2.6 Step 6: Implementing New Procedures

Implementation is an important part of the procedure development process. For a procedure development process to be successful, the new or modified procedures must be effectively disseminated, properly trained, and appropriately promoted. In this section, the issues that arise in implementing procedures are considered and a framework for the implementation process is briefly described.

2.6.1 Implementation Issues

2.6.1.1 Resistance to Change

Many good ideas don’t get implemented, or if implemented—fail, because the people who bring the new ideas assume that everybody will immediately see their value and recognize their merit and be happy to adopt them. This is rarely the case. In fact, change by its very nature creates conflict. For many reasons, people often resist change. Resistance that is not addressed could lead to selective non-compliance. To preempt this resistance, the reasons for resisting change must be carefully considered well in advance of proposing the change, and an implementation plan needs to be designed that includes steps aimed at overcoming such resistance.

Common reasons for resisting change include:

Habits. Pilot training invests much time and effort in developing strong habit patterns, and pilots invest much time and effort in acquiring these habit patterns and turning them into skills. So, pilots are reluctant to change these habit patterns unless they can be convinced that the change is of sufficient value to justify the effort involved in unlearning old habits and acquiring new ones.

Perceived risk. Any change involves some risk. Pilots might misunderstand the new procedures and make mistakes. Under stress, pilots might occasionally fall back onto their old habit patterns, mix the actions required by the old and new procedures, and create confusion. A change that is not carefully thought out may create conflicts among new procedures, between new and old procedures, or between the new procedural demands and company policy or philosophy. If the potential risks are not properly assessed, managed, and communicated, pilots may fail to follow new procedures because they believe them to be riskier than the procedures that they replaced.

Superfluous change. In a successful airline, the vast majority of pilots will likely feel that they are doing a good job and that things are working out well. The pilots may feel that whatever “problem” the change is claiming to address is not a problem they are experiencing. Sometimes the problem or the circumstances that triggered the procedure design project are not easily perceived by line pilots. In other cases, pilots might actually see the problem, but fail to appreciate its significance. Thus, the change might be seen as superfluous.

Better alternatives. Pilots may believe that they have better solutions than the proposed change. They may feel that the proposed change is imposed from above by people who don’t really understand the reality of the operation and therefore should not be trusted.

For example, in many mergers a company flying one type of aircraft buys a company that has been flying another type of aircraft. If the purchasing company imposes its procedures on all pilots, the pilots from the acquired company may feel that the new management does not know how to operate their aircraft and does not understand the nature of their operation. Hence, these pilots may believe that their old procedures are superior to the new procedures that they are required to follow. This belief can breed intentional non-compliance.

2.6.2 Training

Training is an important part of the procedure implementation process. The better the training, the smoother the transition, and the easier the acceptance of the change.

2.6.2.1 Content

Training for a new procedure should include:

1. A detailed description of the new procedure.
2. When the new procedure should be performed.
3. How to perform the new procedure.
4. Why the new procedure was adopted.
5. Who to contact for more information.

2.6.2.2 Scope

The scope of the training for the new procedures depends on the scope of the change. A small simple change may only require minimal training, whereas a large scale change may require extensive training.

At many airlines, pilots complain about “training by bulletin.” That is, all too often a change to procedures is made and announced to the pilots via a bulletin, which usually says something to the effect of “from now on do X.” There is very little, if any, explanation about the background for the change, why it was needed, or what problem it is trying to solve. Worse yet, there is no rationale to explain the particular choices made and no evidence that the change has been carefully and thoroughly thought out. These kinds of bulletins breed apathy and resentment. Pilots resign themselves to the seeming arbitrariness of management, and surrender their intellect and judgment.

Although a simple minor change can be “trained by bulletin,” this bulletin must be carefully composed. It must demonstrate that even though the change is minor, the company has taken the time and effort required to think it through carefully and comprehensively. The bulletin is an

opportunity for the company to transmit the message that it appreciates its pilots, and respects their intellectual ability.

Larger scale changes to procedures require extensive training. In many cases, this training can be accomplished using computer based/distance training products. If the changes are substantial, either because of their scope or their difference from the previous procedures, it would be very useful to include video clips showing how the new procedures should be performed.

In some cases, it may be necessary to provide demonstrations and practice in procedure trainers or flight simulators. This may be the case when crew certification is required for a new type of operation, or when new equipment is introduced that substantially changes the pilot's role or actions.

2.6.2.3 Layered Training

Training can be presented in layers. The top layer is mandatory for all pilots, whereas only those who want to know more need access the deeper layers. The top layer should present the basic information about what needs to be done and how to do it. A second layer could provide basic background about the need for the change and the way the particular change addresses that need. A third layer could provide a description of the process through which the change was designed, including examples of data collected in the analysis of the problem and in crafting the solution, and an outline of the testing the change has undergone. These descriptions can include pictures and video clips taken during team meetings and in the simulator during testing. A fourth layer could then provide detailed rationale for the choices made, including a discussion of the possible solutions considered and rejected with the rationale for the rejections.

2.6.2.4 Evaluation

The effectiveness of the training should be evaluated before it is used broadly throughout the airline.

2.6.3 Dissemination

Relevant company manuals and publications must reflect the changes to the procedures. To be consistent, the new procedures should be written in the same style and format as existing procedures, in accordance with company policies and philosophy, and compliant with regulatory requirements. Care should be taken to provide the appropriate level of information in the relevant publications. For instance, detailed explanations of background and rationale may be best published in a training manual rather than in the operations manual.

2.6.4 Procedure Implementation Process

To increase the likelihood of a successful implementation, the procedure implementation process should begin when the procedure development process begins. The choices made by the procedure developers early in the process can affect the ease with which the procedures are implemented.

Changes are likely to encounter resistance and even apprehension. To facilitate the implementation of new procedures, an educational campaign might be needed to address such resistance and to alleviate any apprehension. Such a campaign must be carefully planned. To be successful, it has to engage many tools to reach the line pilots from as many directions and in as many ways as possible. Large changes such as in the case of a merger must be promoted throughout all levels of

management and the pilots' unions to show the complete commitment of the company to the success of the change.

2.6.4.1 Personnel

To facilitate the implementation of large scale procedural changes, a broad representation of the pilot group including Captains, First Officers, instructors, check airmen, management, and union should be included in the development process.

By the inclusion of line pilots, the argument that the new procedures were designed by people who don't understand the reality of line operations can be countered. Including both FOs and Captains from a broad geographical representation of the pilot group counters the "not invented here" argument. When both management and union representatives participate in the effort, they can serve as ambassadors to their respective constituents and facilitate buy-in by all. When instructors are included, they can provide insight into training considerations throughout the process. Then, they can help build appropriate training. Check Airmen can provide insights into standardization and evaluation considerations.

2.6.4.2 Data

The suggested processes of data collection in the effort to understand the problem (Step 3 above) and in the effort to craft a solution (Step 4 above) can also support successful implementation.

The argument that there was no problem that needed to be fixed can be countered by presenting (in summary form) the careful analysis of the issues triggering the whole procedure development effort. The extent of the data collection effort, such as the different databases searched and the combination of aircraft (FOQA/FDAP/FDM), pilot reports (ASAP/ASRS), and observational (LOSA, Line Checks, training) data used can further demonstrate the extent of the issues, as well as the thoroughness of the development effort. Both can provide important arguments in favor of the proposed change.

2.6.4.3 Documentation

Careful documentation of the whole review and development process, and in particular—the documentation of the rationale for the various decisions made—also serves the implementation process.

Particular emphasis should be placed on documenting the rationale for rejecting possible solutions. Some such possible solutions are likely to have come from line pilots' techniques and workarounds, and many of them are likely to be brought up by pilots once the new procedures are implemented. By disseminating the rationale for the new procedures and for rejecting alternatives, many potential critics may be satisfied and the likelihood of resistance to the changes greatly diminished.

Parts of the procedure development process itself can become parts of the training. For instance, at various points during the testing of the proposed procedures, procedure developers can document their own learning. This information can be used in developing the training materials. Video recordings of the testing and validation of the procedures can be embedded in the training. These video clips can be used to demonstrate the thoroughness of the process. If the procedure performed is the final product, the video becomes a demonstration of how the procedure should be executed.

Also, careful documentation of the development process serves as the basis for the application to the FAA for approval of the new procedures. New cockpit procedures must be approved by the operator's designated POI prior to implementation. To be able to implement the proposed procedure smoothly, it's best to engage the POI early in the process, provide the POI with regular updates, and include in the final application the complete documentation of the whole development process. Such involvement allows the POI to ascertain the thoroughness of the process and the quality of the proposed changes.

2.7 Step 7: Evaluating and Monitoring the Conduct of Procedures in Practice

New procedures need to be evaluated prior to their release, and also following their implementation. Evaluation should not be regarded as an unnecessary task that can be performed if there is time and extra resources. Evaluation is a critical part of the process and an important guard against the potential failure of the whole endeavor.

No matter how many smart people are working on the procedure design and development project, errors will occur. The only way to catch mistakes and avoid costly new problems is to perform a careful evaluation. The procedure developers might all agree that the new procedures are reasonable, but the procedures must be tested in a simulator, tried by other pilots, and tested on the line, where the world is much more complex than in the simulator. The new procedures must be given a chance to fail.

A well-designed outcome evaluation is a systematic way to find problems in proposed procedures before they are implemented. The evaluation allows for testing whether the new procedures work in the environment for which they were designed and with the people who will be using them. A thorough evaluation can discover problems that were not anticipated and generate solutions before the problems produce serious consequences.

Evaluations are conducted to provide accurate assessments of the expected effects of an intervention. In general, the best evaluations are conducted using multiple methods. To perform them, one can use simulations, questionnaires, archival data, and line observations. Evaluations are conducted late in the development process, once the procedure developers have settled on a set of procedures that they believe will work. Procedure evaluations occur both before and after the new procedures are implemented on the line.

2.7.1 Evaluation Process

The evaluation process can be divided into 6 steps:

1. Determine what to measure.
2. Create a research design.
3. Develop measures.
4. Collect data.
5. Analyze data.
6. Report the results.

2.7.1.1 What to Measure

In general evaluations are designed to obtain measures of procedural compliance and errors in the execution of procedures, as well as measures related to the other goals of the procedure design or redesign effort—i.e., meeting the requirements of correctness, reliability, robustness, resilience, effectiveness, efficiency, etc.

The evaluation cannot rely solely on measures of ultimate consequence such as accidents or incidents. Commercial aviation in the United States is an extremely safe enterprise. Hence, the likelihood of encountering any serious consequence during an evaluation is extremely low. Rather than rely on measures of ultimate consequence, the evaluation must rely on measures of factors that increase the risk of a serious consequence. Risk is a function of the probability and consequence of an adverse event. Thus, the risk of an accident is increased whenever the likelihood of having an accident or the seriousness of the consequences of the event is increased. Procedural errors may increase the likelihood of an accident.

For example, a procedure may call for the flaps to be set for takeoff prior to leaving the departure gate area. Failing to do so increases the risk of an accident because the pilot must now remember to configure the aircraft for takeoff without procedural support. Of course, it is still unlikely that this procedural error will produce an accident. The pilot might remember, the crew might notice the error while performing a pre-takeoff checklist, or the Take Off Warning System may alert the crew to the problem when the throttles are advanced. However, the failure to properly execute this procedure increases the risk of an accident. Thus, one could use a count of the number of errors made on critical procedures as an indirect measure of safety. If a change in the procedures increases the likelihood of an error occurring or the number of observed errors, the risk has increased.

2.7.1.2 Research Design

To evaluate procedures, we are generally interested in comparing operations using one set of procedures, to operations using a different set of procedures. This typically involves comparing operations conducted at one airline under new procedures to operations conducted at the same airline under a previous set of procedures. To do that, an initial set of data reflecting operations under the existing procedures must be collected early in the procedure development process, once it is clear what aspects of the operation are likely to be affected by the anticipated change. That way the data collection could target these specific aspects of the operation and establish a benchmark, or a baseline, against which later data could be compared.

Once the new procedures have been implemented, data collection for the evaluation may have to be done in stages or in cycles. For example, it may be prudent to introduce the changes in the spring when weather is mild and there is no holiday travel pressure. Once introduced, the procedures should be evaluated. Such an evaluation also provides important feedback concerning the effectiveness of the training and of the whole implementation effort. The procedures should be evaluated again later, when winter operations are in effect, to test the reliability and robustness of the new procedures under these different operating conditions.

2.7.1.3 Measures

Good measures should be: (1) valid—measuring what they purport to measure; (2) reliable—producing the same result when nothing has changed; (3) sensitive—demonstrating changes when

the thing being measured changes; (4) accurate—not showing systematic biases; and (5) precise—demonstrating little error. These characteristics serve as the criteria for evaluating the measures to be used in the evaluation and provide the basis for choosing one measure over another.

Valid. The measure measures what it claims to measure. For example, in evaluating procedures, one should be concerned that pilot workload at any given time not be excessive. The term “workload” is generally used to refer to the perceptual, cognitive, and physical demands placed on an individual. A measure of workload that examined only one of these aspects would not be a valid measure of “workload” because a task could place demands on the individual in ways other than those measured. If the invalid measure were used, these workload demands could affect performance while escaping notice.

Reliable. The measure consistently produces the same results when the thing being measured has not changed.

Sensitive. The measure is able to detect small changes. The more sensitive the measure, the better it is in detecting changes. For example, one could use falling asleep on the job as a measure of fatigue. There is little dispute that falling asleep at the controls is often a result of fatigue. However, pilots can be quite fatigued and display impaired cognitive and motor performance long before they fall asleep. Counting the number of incidents of pilots sleeping at the controls is a relatively insensitive measure of pilot fatigue. There are many measures of fatigue (e.g., self report, eye-lid droop, reaction time, electroencephalography) that are much more sensitive measures of fatigue than are episodes of unplanned sleep. Sensitive measures allow measuring the effects of procedural changes with fewer observations over shorter time periods than would be required if only less sensitive measures were used.

Accuracy and precision. There is error in every measurement. This error can be random, i.e., as likely to produce an underestimate as an overestimate, or biased, systematically over or underestimating the true value. Accuracy measures the degree of systematic error. Precision measures the degree of random error. For example, some observers sitting on the jumpseat may have difficulty judging the aircraft’s speed during taxi. Sometimes they underestimate the aircraft’s speed and sometimes they overestimate the aircraft’s speed. Hence, sometimes aircraft that are taxiing too fast are judged to be taxiing safely and sometimes aircraft that are taxiing at safe speeds are judged to be taxiing too fast. These observers are accurate (as likely to make errors in one direction as the other) but imprecise (making large errors). Other observers may consistently underestimate the speed of the taxi, judging aircraft that are taxiing too fast as taxiing at safe speeds, and judging aircraft that are taxiing at safe speeds as taxiing too slowly. These observers are inaccurate (systematically biased) but may be quite precise (making small errors). Any combination of accuracy and precision is possible. Ideally, measures would be accurate and precise.

2.7.1.4 Data Collection

As noted previously (see Step 3 above), there are several different sources of data that are generally available for use in evaluating procedures. These include flight data recorded from aircraft systems and instruments (e.g., FOQA/FDAP/FDM data), cockpit observations (e.g., LOSA; line checks), and self-reports (e.g., ASAP reports, responses to questionnaires).

The logistics involved in collecting data should not be underestimated. If substantial changes are made to procedures used throughout the company, data will need to be gathered from all parts of all of the fleets. Of course, if changes are made only to a particular procedure used by only one type of aircraft, then data may be obtained from only the affected fleet and the affected operation.

The data collection process may require the cooperation of information technology, safety, scheduling, flight operations, and other units. For example, if experienced pilots are to be used as observers, they will need to be freed from their normal duties long enough to be trained and to conduct the observations. To efficiently capture all of the different facets of the operation of a large airline, scheduling will need to work to devise sequences of flights so that observers can move from one flight to another with minimal downtime and not too many nights away from base while sampling from all of the types of operations that the airline conducts (e.g., time of day, type of airport, geographic location, etc.). Commercial questionnaire software can be used to produce electronic questionnaires, but information technology will need to be involved if the questionnaire is to be hosted on the company servers and the data properly saved and confidentially downloaded for analysis. If flight data records are used, the data will need to be summarized and de-identified to protect pilots' confidentiality. This will probably require the cooperation of the safety department (or a flight data management department) and possibly the pilots' union.

2.7.1.5 Data Analysis

The job of the data analyst is to accurately summarize and present the data. In general, this will involve calculating descriptive statistics; e.g., counts of events, measures of central tendency (e.g., means, medians, modes), and measures of dispersion (e.g., standard deviation, ranges).

Most of the questions that are needed in an evaluation, such as “is the number of errors made greater under the old procedures or the new procedures” can be answered simply by inspection of the relevant descriptive statistics. Inferential statistics are used to determine whether the observed differences are so large relative to the variation within the groups so that it is unlikely that the difference is just a product of random variation across the observations. For example, the average number of procedural errors made by crews using new procedures may be lower than the average number of errors made by crews flying with the old procedures. However, some crews may have made substantially more errors than others. In fact, some of the crews flying with the new procedures may have made more errors than some of the crews flying with the old procedures. An inferential statistic can be used to determine, at a specified probability level, whether the observed difference between the old and the new procedures is such that it is unlikely to have happened by chance. However, it must be remembered that a difference can be “statistically significant,” meaning that it is unlikely to be due to random fluctuations, and very small, thus not operationally meaningful.

2.7.1.6 Reporting Results

The results of any evaluation will need to be communicated. Possible audiences include procedure designers, management, regulators, training, and the pilots themselves. Good communication begins with understanding the needs and capabilities of the audience. It should answer the questions that the audience is asking, and provide the information in a manner that the audience can easily understand. In every case, the presentation of the evaluation should be focused on the important questions and be as simple as possible without sacrificing accuracy. Descriptions of the sources of data and the

methods used should accompany the results. Results should be organized to allow easy recognition of the important comparisons.

2.7.1.7 Cycles of Evaluation

Evaluating the effectiveness of interventions is an iterative process. Operators can incorporate such evaluations into regular cycles of LOSA, collect data from line checks and training events, and continuously monitor FOQA and ASAP data for relevant indicators. Operators should also consider periodic surveys of the pilots to elicit information about practices on the line and to monitor for any changes that would merit the review and redesign of operating procedures. The aviation industry and the operational environment are dynamic. Technology changes at an ever-accelerating pace, and the pilot group is constantly changing as well. Policies and procedures must be continuously updated to keep up and to stay ahead of all these changes.

3.0 Conclusion

This report has sought to summarize a long and complex project. Like any summary, it cannot cover all of the nuances in detail. However, we trust that it has delineated the main points in sufficient detail to allow readers to understand the essence of the topic. It is our intention to continue this work and to produce fuller treatments of all of the topics described here.

At the birth of aviation, pilots did not follow systematic procedures. However, they learned quickly that some ways of doing things were substantially better than others. These “ways of doing things” were communicated to the next generation of aviators and eventually written down. As aviation grew and became organized by the military, the mail services, and eventually airlines, these written procedures became prescriptions. At this point in time, no one in aviation questions the importance of having good procedures. But procedure development remains more of an art than a science and even the definition of what makes a good procedure remains unclear. This is the current challenge for procedure development in aviation and it is the challenge that we have sought to address in the work described here. Although it may never be possible to produce a formula for creating good procedures, the work reported here indicates that “procedures for procedure development” can be developed which can systematically improve operational procedures and thereby improve operational safety and efficiency.

Appendix

Procedure Design Process Summaries

I. Requirements for Procedures

Procedures are developed to accomplish specific tasks. Every procedure has a primary requirement:

Correct. The specified actions will yield the desired outcome.

Furthermore, every procedure has three basic requirements. Good procedures should be:

Reliable. Under normal conditions, whenever the specified actions are accomplished, the desired outcome will obtain.

Robust. The procedure will succeed in achieving the desired outcome despite minor variations in the performance of the equipment, the actions of the human operators, or in the operational environment.

Resilient. The procedure will succeed in achieving the desired outcome despite errors or unexpected variations.

A procedure is either correct or not. However, reliability, robustness, and resilience are matters of degree. The more reliable, robust, and resilient the procedure, the better the procedure. In addition to these three basic requirements, there are a number of subsidiary criteria that support these requirements. These subsidiary criteria are not independent of each other and one criterion may need to be traded off against another. In general, procedures should be:

Efficient. The procedure should require the least amount of time and effort possible.

Useable. The procedure should be “easy” to use.

Coordinated. Procedures should incorporate steps that ensure adequate coordination between participating individuals.

Integrated. Procedures should be well integrated into the workflow.

Consistent. Individual procedures should be consistent with other procedures, as well as with relevant policies and the overall operational philosophy.

Trainable. Procedures should be easy to train.

Adaptable. Procedures should be able to be adapted to foreseeable changes in technology, people, and the operational environment.

II. Design of Procedures

A well-designed procedure aids flight crews by specifying a sequence of actions that if followed ensures that the primary task at hand will be carried out in a manner that meets the above basic requirements and, to the extent possible, meets all of the subsidiary criteria.

In general, good procedures specify 5 things:

1. What the procedure is designed to accomplish.
2. When and/or under what conditions the procedure should be executed.
3. Who is responsible for executing each step in the procedure.
4. How, in detail, the procedure is to be performed.
5. How to confirm that the procedure has been accomplished properly.

In addition, the procedure designer must consider what type of safety margins, barriers, and buffers should be built into the procedure, as well as what types of steps are required. Steps can be of the following types but not all types of steps must be present in any given procedure:

1. Information gathering.
2. Information processing.
3. Conditional branching.
4. Decision making.
5. Waiting.
6. Action.
7. Verification.
8. Validation.

A general approach to the process of developing procedures follows the 5 steps below. These steps are iterated when necessary:

1. Develop a prototype task procedure.
2. Analyze prototype procedure.
3. Eliminate conflicts.
4. Develop phase procedure.
5. Test procedure.

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